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Project FISHBOWL Effects On Omega VLF Transmissions

Phase and amplitude effects during Events STARFISH, BLUEGILL Triple Prime, and KINGFISH

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THE PROBLEM

Determine what effects nuclear detonations have on amplitude and phase stability of Omega signals on 10.2 kc/s and 14.2 kc/s.

RESULTS

1. Phase and amplitude of Omega signals were studied during three events of Project FISHBOWL: Event STARFISH (9 July 1962), Event BLUEGILL Triple Prime (26 October 1962), and Event KINGFISH (1 November 1962). Data were not taken during Events CHECKMATE (20 October 1962) or TIGHTROPE (4 November 1962).

2. Representative recordings of signals transmitted by three Omega stations, as received at eleven monitoring sites, are included with the report. In all cases, any disturbance in propagation characteristics caused by the detonation is noted on the recording.

RECOMMENDATION

Continue the investigation of effects of nuclear detonations on vlf radio propagation, by evaluating the recordings furnished here as part of the over-all effort.

ADMINISTRATIVE INFORMATION

Work was performed under SS 161 000, Task 6101 (NEL A1-4). This report covers intermittent work from June 1962 to January 1963 and was approved for publication 20 December 1963.

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REVERSE SIDE BLANK

INTRODUCTION

The present-day uses of very low frequencies are of growing importance. It is therefore necessary to examine the effects of nuclear events upon vlf phase and amplitude.

The study reported here was undertaken to measure the effects on the vlf carrier used by the Omega navigation system during Project FISHBOWL.

The three events of the FISHBOWL Project under consideration here were designated STARFISH (9 July 1962), BLUEGILL Triple Prime (26 October), and KINGFISH (1 November 1962). The sections covering the various types of measurement include recordings from all three events and describe the instrumentation and procedures employed.

Data were not taken during Events CHECKMATE (20 October 1962) or TIGHTROPE (4 November 1962).

In the descriptions of the tests no extensive analysis of the results is made. However, any faults of system operation, or known irregularities in the recordings, are mentioned or illustrated throughout the various sections, as appropriate.

DESCRIPTION OF OMEGA SYSTEM

The existing Omega system[1,2] is an experimental one using three transmitting stations located at Balboa (Summit), Canal Zone: Haiku, Oahu, Hawaii; and Forestport, New York. It is usable over approximately 25,000,000 square miles of the earth's surface (land and sea). The final system will require six or seven stations and will provide all-weather navigation over the entire globe.

Omega depends on the accurate measurement of the phase difference of signals received from two synchronized transmitting stations to determine a hyperbolic line-of-position. The intersection of two such lines provides a navigational fix. Omega is similar in principle to Loran, but differs from it in using 1-second pulses in the very-low-frequency band and in using carrier phase difference instead of time difference measurements.

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[1] Navy Electronics Laboratory 1153, Technical Evaluation of Omega Navigation System, by Omega System Group, 18 December 1962.

[2] Casselman, C. J. and others, "VLF Propagation Measurements for the Radux-Omega Navigation System," Institute of Radio Engineers. Proceedings, v.47, p.829-839, May 1959.

Each Omega station transmits its signals in a precisely timed sequence and then stands by while the other synchronized stations transmit in turn. At the time of the FISHBOWL detonations, time segments were as shown in figure 1.

Each station's transmission differs slightly in length to aid in recognition at the receiver. The leading edge of segment A was synchronized with the 18-kc/s NBA time signal to occur at 00 seconds and multiples of 5 seconds (±20 msec) thereafter. The navigation receiver automatically measures the phase difference of the carriers from pairs of stations, master and slave, and indicates it on dials and a strip chart. When integrated over a number of transmission periods the phase difference measurement becomes very accurate. Since the Omega navigation receivers use synchronous detection followed by narrow banding in the servo system (to the order of 0.01 c/s), good phase tracking is obtained with signal-to-noise ratios of -20 dB (100-c/s bandwidth).

From the phase difference information, the navigator may determine the indicated line-of-position by the use of special charts.

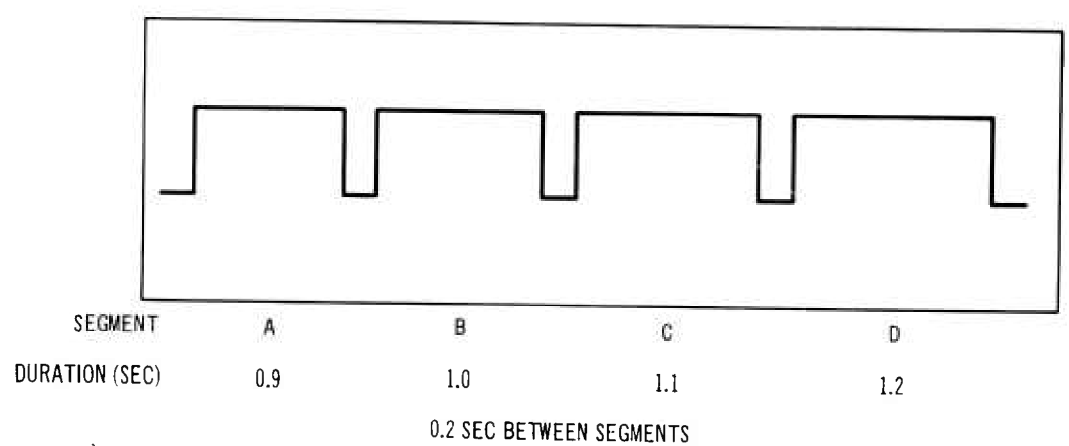

Figure 1. Omega commutation pattern.

Shore Installations

At the time of the tests reported here, the experimental Omega network consisted of three stations, a master and two synchronized slaves, each transmitting sequentially on a single 10.2-kc/s frequency. The transmitting pattern was repeated every five seconds. Each station derives its transmitting frequency and timing from a precision frequency standard. The master station and both slave stations utilize the AN/FRA-31 100-kW transmitter developed for the Omega program. The power radiated from Balboa, Canal Zone, is normally 1.4 kW and from Haiku, Hawaii, 4 kW. The power radiated from Forestport, New York, varies from 5 to 165 watts, depending on local weather conditions. However, under normal conditions it may be considered to be approximately 100 watts.

Fixed Site Monitors

The shipboard navigation receiver, AN/URN-18(XN-1), was used for the fixed site monitor in most of the tests. A 35-foot vertical whip was used for an antenna in all cases. Two phase recordings were provided by each receiver. Readout was provided by dials which indicated cycle count, and by a dual-strip chart recorder which presented traces of the two phase difference readings from 0 to 100 per cent of a cycle (100 per cent = 360°). Another single recorder provided a record of "master phase"; that is, the difference between the received phase of the designated master station and the reference frequency standard of the navigation receiver.

At the two slave stations, the readouts of the synchronizer servo systems are used to provide master phase data. This is a normal output obtained during the process of synchronizing transmissions. The receiving sites are located a few miles from their respective transmitters, at Opana for the Hawaii slave station, and at Rome for the New York slave station, and must be considered as one end of the transmission path. The reference frequency standard at Haiku and at NEL is the Western Electric 0-451/U and at Forestport, the Western Electric GS-52879. These frequency standards have a short-term stability of about 1 part in 10^{10} and a long-term drift rate of about 3 parts in 10^{11} per day. The frequency standard used with the navigation receiver has a stability of 1 part in 10^{8}, which is somewhat lower and must be taken into consideration when analyzing the "master phase" tracks.

System Operation for Tests

Event STARFISH

During Event STARFISH the Omega slave station at Haiku, Hawaii, was inoperative because of primary power failure. The master station at Balboa (Summit), Canal Zone, and the slave station at Forestport, New York, therefore produced only

one line of position. Balboa was transmitting on segment D and Forestport on segments A and C, both at 10.2 kc/s. No change from normal operation of the Omega system was made during this test.

Events BLUEGILL Triple Prime and KINGFISH

All stations were operative during Events BLUEGILL Triple Prime and STARFISH, with time segments and frequencies indicated below:

Station	Segments	Frequency (kc/s)
Balboa, C.Z.	D	10.2
Forestport, N.Y.	A	10.2
Haiku, Hawaii	D and A	14.2
	B	10.2

The master station at Balboa transmitted segment D and the slave station at Forestport transmitted segment A, both at 10.2 kc/s. Forestport operated as a normal Omega slave (synchronized on the master station) for the entire tests. Operation at the slave station at Haiku was modified so that it transmitted sequentially at both 10.2 and 14.2 kc/s. The 10.2-kc/s transmission was on segment B; synchronized operation was maintained except for a period approximately 15 minutes before to 45 minutes after the events (011155 UT to 011335 UT for Event KINGFISH; 260943 to 261104 UT for Event BLUEGILL). During this one-hour period, the master servo system was turned off and changes in the propagation path from the master station at Balboa to the slave station at Haiku were not retransmitted. Therefore, a nonsynchronized transmission period was provided during Events BLUEGILL and KINGFISH, allowing measurements to be made on the one-way transmission paths from Haiku to the monitoring stations.

Haiku transmitted on 14.2 kc/s during segments D and A. This 14.2-kc/s frequency was derived directly from the 0-451/U frequency standard used as a reference at Haiku. Therefore, the 14.2-kc/s transmission constituted a master transmission during the entire time, and any phase recordings should be considered as one-way transmission paths. During the one-hour period when the 10.2-kc/s transmissions were not synchronized, both the 10.2-kc/s and the 14.2-kc/s transmissions were derived from the same frequency standard.

MEASUREMENT PROCEDURES AND INSTRUMENTATION

The following sections describe the instrumentation and procedures involved in making the various measurements. The recordings were made at the Navy Electronics Laboratory, San Diego, and its field stations.

The sequential method of transmission used by the Omega system is described on page 2. At the time of the FISHBOWL detonations, the transmission segments were as shown in figure 1.

The time constants and various servo systems used vary considerably from approximately 2 seconds to 60 seconds. For comparison purposes only, under similar operating conditions and adjustments, table 1 lists the approximate time constants.

Table 2 shows the distances between transmitters and monitoring sites.

TABLE 1. TIME CONSTANTS

Receiver Used	Time Constant (sec)	Remarks
AN/URN-17(XN-1)	60	14.2-kc/s recordings
AN/URN-18(XN-1)	30	All recordings
Omega synchronizer master channel	15	10.2-kc/s Balboa transmission
Omega synchronizer slave channel	2	10.2-kc/s Haiku transmission
Omega synchronizer slave channel	2	14.2-kc/s magnetic tape recording of Haiku transmissions

TABLE 2. DISTANCES BETWEEN TRANSMITTERS AND MONITORING SITES

Transmitter	Distance from Transmitter (km) Monitoring Site			Geographical Position of Transmitter and Monitoring Site
	HAIKU	BALBOA	FORESTPORT	
Haiku, Hawaii		8436	7835	21°24' 28.67"N 157°50'80" W
Balboa (Summit), C. Z.	8436		3836	9°03'14.67"N 79°38'53.22"W
Forestport, New York	7835	3836		43°26'42" N 75°05'10" W
College, Alaska	4870	8060	4940	64°51'26" N 147°49'17" W
Whidbey Island, Washington	4320	5900	3640	48°16'52" N 122°37'17" W
Rome, New York	7813	3808	36	43°13'26.4" N 75°24'36.8" W
NEL, San Diego, Calif.	4188	4666	3840	32°42'28.65"N 117°14'47.27"W
Opana, Hawaii	36	8452	7829	21°41'21.36"N 158°00'42.78"W
Farfan, C. Z.	8447	15	3849	8°55'52.83"N 79°35'03.32"W
Pt. Barrow, Alaska	5547	8595	5213	71°18'25" N 156°44'29" W
Thule, Greenland	7681	7523	3696	76°30'45" N 68°42'32" W

FIELD INTENSITY RECORDINGS

Figures 2-13 are reproductions of original traces of the signal amplitude recordings made during all three events. (See table 3.) Except for figures 5, 9, and 13, all the recordings were made by a special field intensity meter[3] developed at NEL to operate in conjunction with the AN/URN-18(XN-1) navigational set. The meter was calibrated by an AN/URM-102 field intensity meter.

The field intensity meter consists of a calibrated attenuator, a linear "in-phase" (coherent) detector, a dc amplifier, and a recorder using special chart paper calibrated in decibels.

Since an in-phase coherent detector is used for amplitude detection throughout, a change in phase difference between master and its reference, as well as a decrease in signal input, will cause a decrease in indicated amplitude on the recording. Therefore, it must be noted that during times of sudden phase changes an indicated drop in amplitude may be caused by lag of the phase monitoring servo, as well as by an actual decrease in signal amplitude. A 45° change in reference phase, for example, will cause a decrease of 3 dB in indicated amplitude.

Since the radiated power of transmissions from the Forestport, New York, station are so variable (because of antenna voltage limitations due to weather), the antenna currents for 8, 9, and 19 July (from 0500 UT to 1500 UT) are included in table 4 for use in evaluating figure 4 (field intensity recordings from Forestport). The time constants of the field strength meter and phase servos must also be considered. Time constants used are indicated on the recordings.

Recordings of the field intensity for the day preceding and the day following the event are shown for comparison on each figure.

The master station at Balboa, C. Z., is off during the 5th through the 7th minutes of each hour (XX:04 to XX:07), and during the last five minutes of each hour Omega transmissions are deleted for the last 10 seconds of each minute. Recordings of field intensity of the Panama transmitter therefore show a drop once an hour during the 5th through 7th minutes, as well as a decrease at the end of the hour. Amplitude starts increasing again at the start of the hour (00 minutes). Figure 5 indicates the missing pulses at the end of the hour as five small notches.

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[3] Navy Electronics Laboratory 1158, Field Strength Recorder for Very Low Frequencies, by J. C. Hanselman, 11 February 1963.

Figure 13 is a plot of intensity recordings taken from constant-speed, continuous-motion photographs for Event KINGFISH. (A subsequent section describes this photographic method.) Film speed for these photographs was 30 inches per second.

In one case only (fig. 5) recordings were made by equipment in the synchronizer and indicate relative amplitude only, since they reflect nonlinearity of the receiver and noise, as well as phase of the reference, as mentioned earlier.

The accuracy of the chart times has not been verified.

TABLE 3. SUMMARY OF DATA PRESENTED IN THE AMPLITUDE RECORDINGS

Fig. No.	Transmission Path	Length of Path (km)	Approx. Dist. from Detonation to Nearest Point of Path (km)	Max. Recorded Decrease in Amplitude (dB)	Date and Time of Maximum Recorded Decrease in Amplitude (UT)
2	Balboa to NEL	4666	5526		---
3	Balboa to Pt. Barrow	8595	5893		---
4	Forestport to Pt. Barrow	5213	5893		---
5	Balboa to Forestport, N. Y.	3836	9118		---
6	Haiku to College, Alaska	4870	1357	8	261008 Oct 62
7	Haiku to Whidbey Is.	4320	1357		261003 Oct 62
8	Haiku to Rome, N. Y.	7813	1357	3	261000 Oct 62
9	Haiku to NEL	4188	1357	10	011218 Nov 62
10	Haiku to College, Alaska	4870	1357	5	011210 Nov 62
11	Haiku to Whidbey Is.	4320	1357	10	011210 Nov 62
12	Haiku to Rome, N. Y.	7813	1357	3	011210 Nov 62

TABLE 4. FORESTPORT ANTENNA CURRENT DURING EVENT STARFISH

8 July 1962: Approximately constant at 62 amperes.

9 July 1962: As listed below.

Time (UT) From	Time (UT) To	Antenna Current in Amperes	Antenna Current in dB re 1 Ampere
082205	090744	62	35.8
090744	090749	56	35.0
0749	0757	32	30.2
0757	0800	12	21.6
0800	0810	34	30.6
0810	0814	20	26.0
0814	0829	off	
0829	0840	35	30.8
0840	0845	46	33.2
0845	0855	22	26.8
0855	0951	32	30.2
0951	1010	40	32.0
1010	1208	45	33.0
1208	1301	50	34.0
1301	1329	58	35.2
1329	1344	66	36.4
1344	1500	65	36.2

10 July 1962: Approximately constant, varying between 54 and 62 amperes.

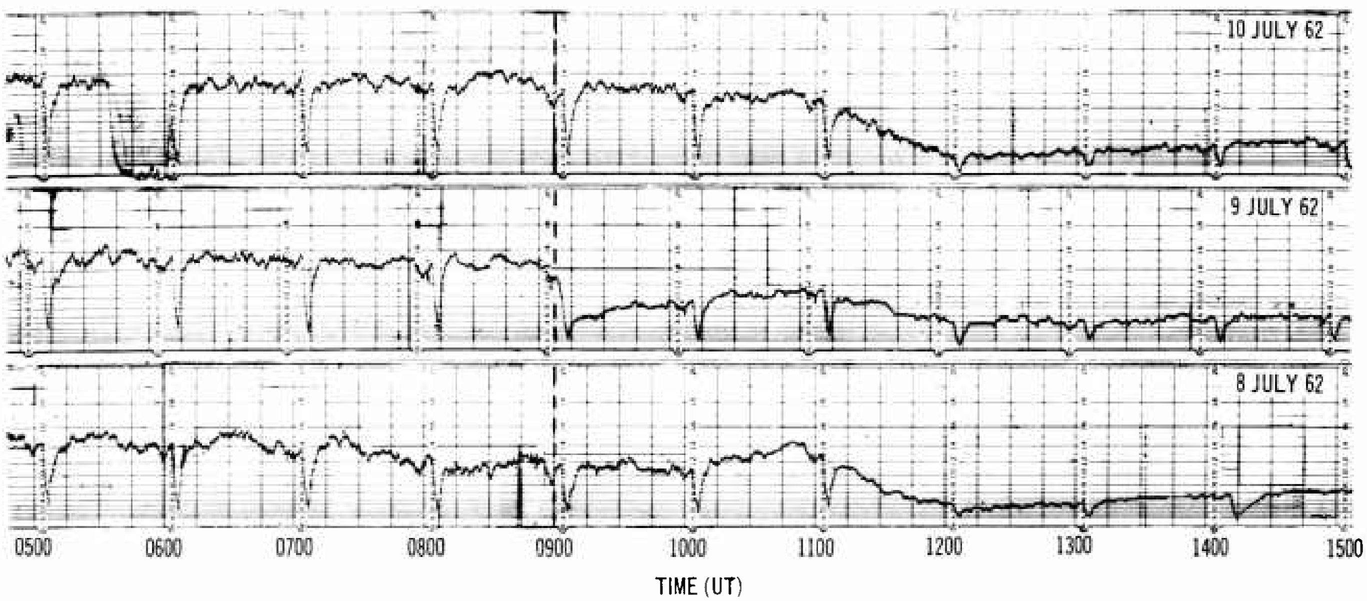

Figure 2. Field intensity recordings of 10.2-kc/s transmissions from Balboa, C.Z., taken at NEL, San Diego, 8-10 July 1962. Calibration: add 26 for dB above 1 μV/meter; time constant, 50 sec; receiver, NEL field intensity meter and AN/URN-18(XN-1) receiver.

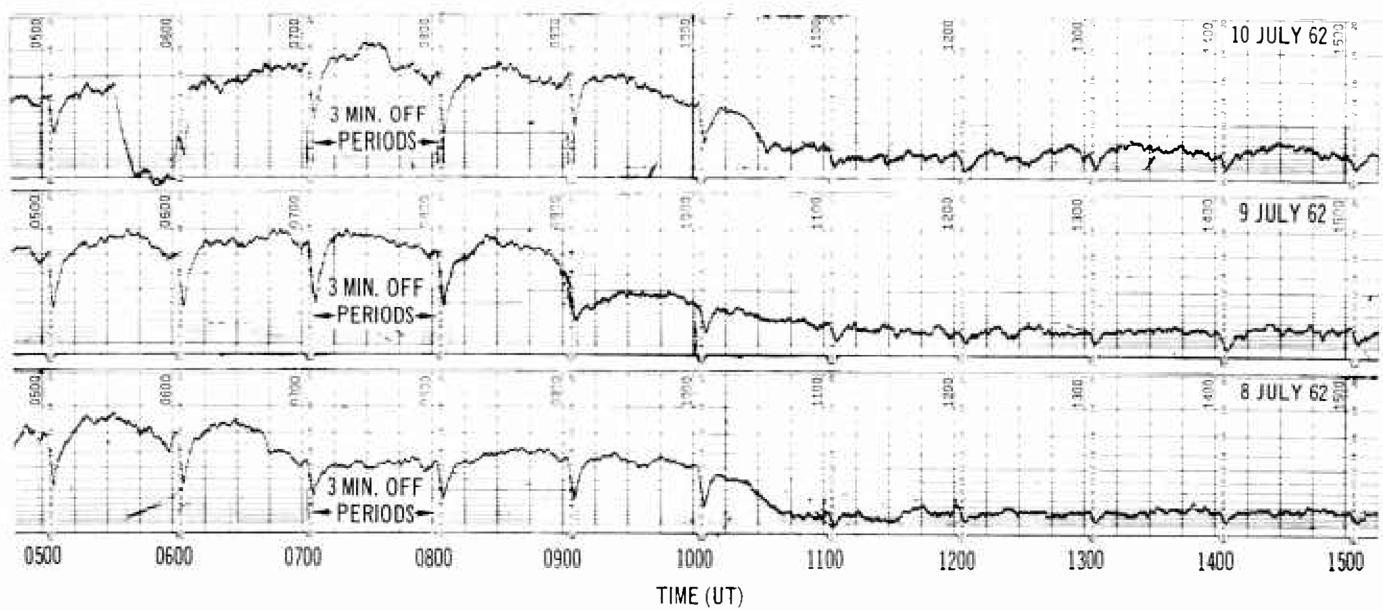

Figure 3. Field intensity recordings of 10.2-kc/s transmissions from Balboa, C.Z., taken at Pt. Barrow, Alaska, 8-10 July 1962. Calibration: add 10 for dB above 1 μV/meter; time constant, 50 sec; receiver, NEL field intensity meter and AN/URN-18(XN-1) receiver.

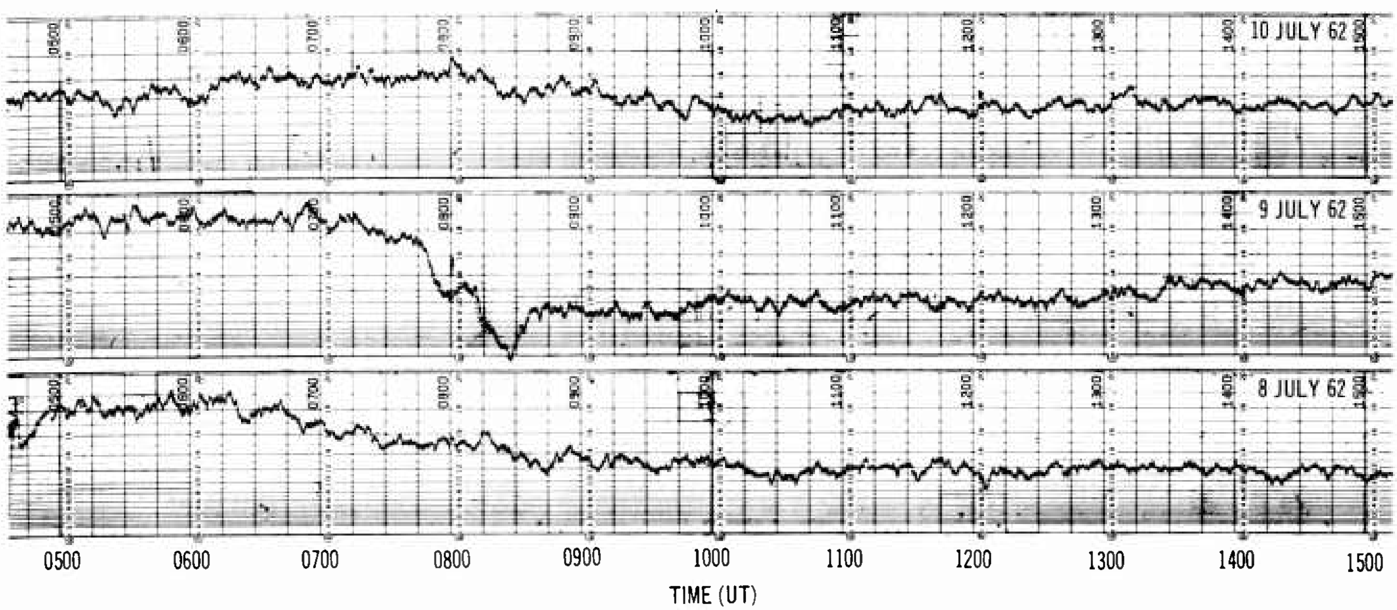

Figure 4. Field intensity recordings of 10.2-kc/s transmissions from Forestport, N.Y., taken at Pt. Barrow, Alaska, 8-10 July 1962. Calibration: add 10 for dB above 1 μV/meter; time constant, 50 sec; receiver, NEL field intensity meter and AN/URN-18(XN-1) receiver.

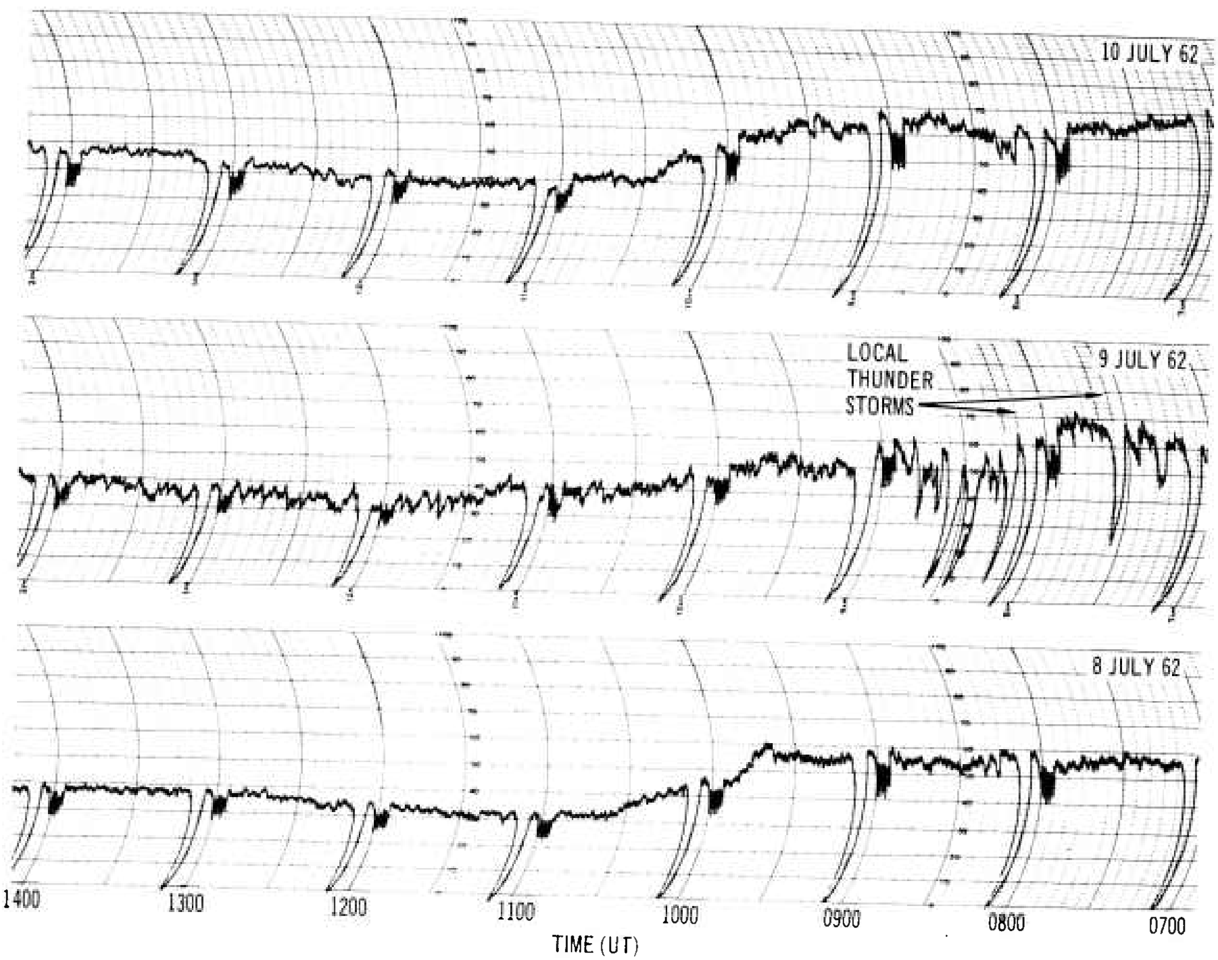

Figure 5. Amplitude recordings of 10.2-kc/s transmissions from Balboa, C.Z., taken at Forestport, N.Y., 8-10 July 1962. Time scale, 5 min./division. Receiver, NEL synchronizer. The recording is essentially linear but only relative amplitudes are indicated since the receiver had not been calibrated by comparison to a standard field. As in figs. 2-4, the recording shows a drop at the beginning of each hour when the Omega transmitter was off for 3 minutes. The five small notches in the recording at the end of each hour show the effect of two Omega pulses being deleted during the last 10 seconds of the 55th through 59th minutes of the hour. (The effect is not so pronounced on figs. 2-4 because of the greater time constant involved.)

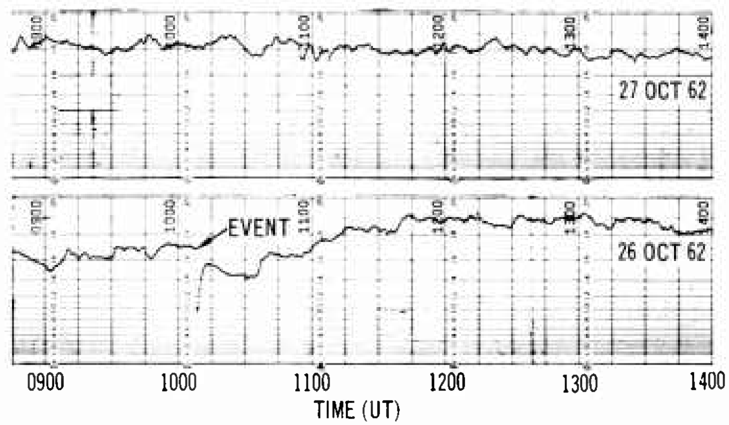

Figure 6. Field intensity recording of 10.2-kc/s transmissions from Haiku, Hawaii, taken at College, Alaska, 26-27 October 1962. Time constant, 10 sec; calibration: add 30 for dB above 1 μV/meter; receiver, NEL field intensity meter and AN/URN-18(XN-1).

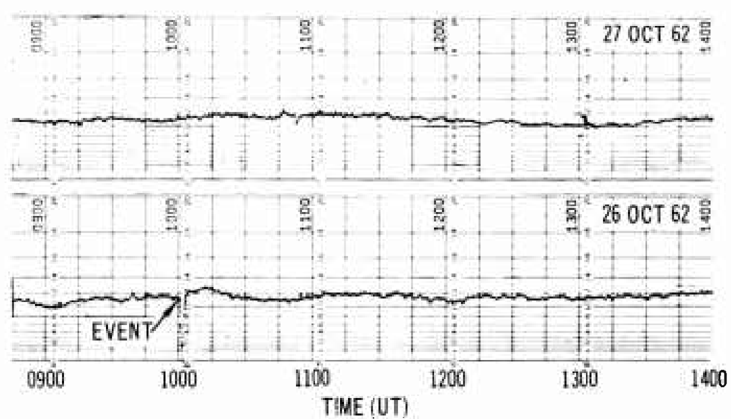

Figure 7. Field intensity recording of 10.2-kc/s transmissions from Haiku, Hawaii, taken at Whidbey Is., Wash., 26-27 October 1962. Time constant, 5 sec; calibration: add 35 for dB above 1 μV/meter; receiver, NEL field intensity meter and AN/URN-18(XN-1).

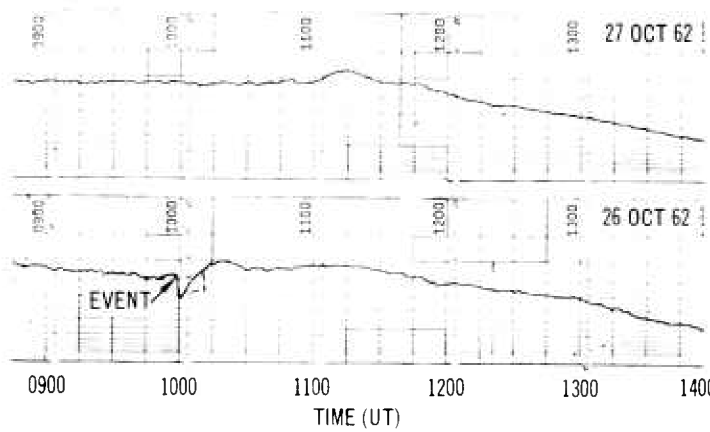

Figure 8. Field intensity recording of 10.2-kc/s transmissions from Haiku, Hawaii, taken at Rome, N.Y., 26-27 October 1962. Time constant, 50 sec; calibration: add 25 for dB above 1 μV/meter; receiver, NEL field intensity meter and AN/URN-18(XN-1).

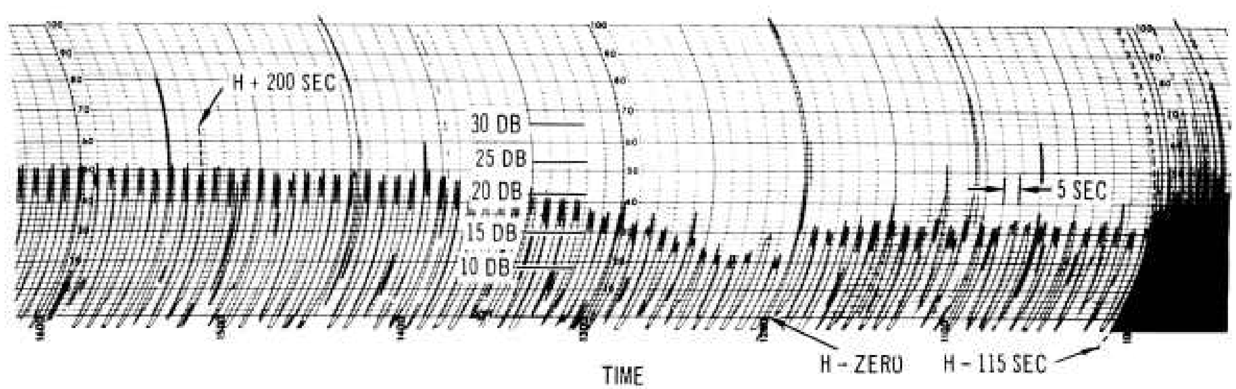

Figure 9. Field intensity recording of 14.2-kc/s transmissions from Haiku, Hawaii, taken at NEL, San Diego, 1 November 1962. Bandwidth, 60 c/s; no calibration; scale is relative only. Receiver, AN/URM-41 field intensity meter at chart speed of 3 in./min.

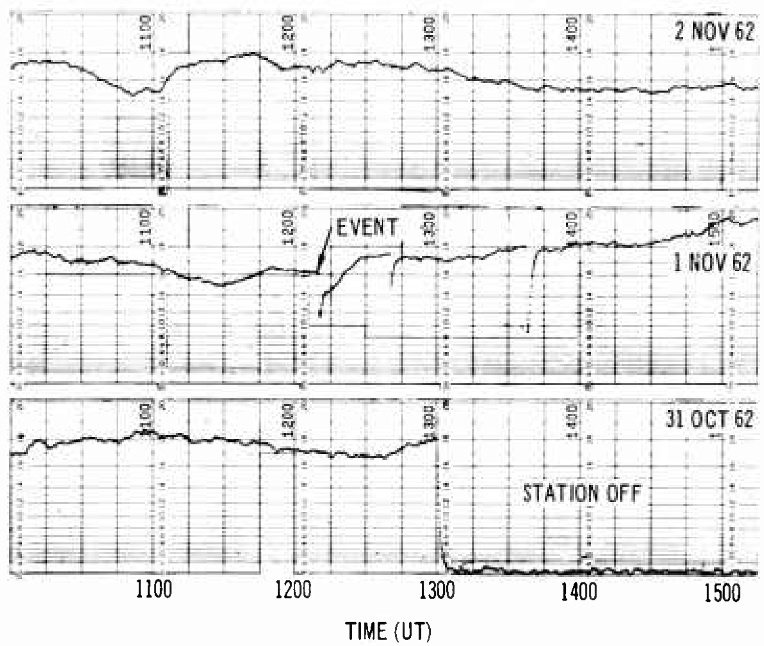

Figure 10. Field intensity recording of 10.2-kc/s transmissions from Haiku, Hawaii, taken at College, Alaska, 31 October and 1-2 November 1962. Time constant, 10 sec; calibration: add 30 for dB above 1 μV/meter; receiver, NEL field intensity meter and AN/URN-18(XN-1).

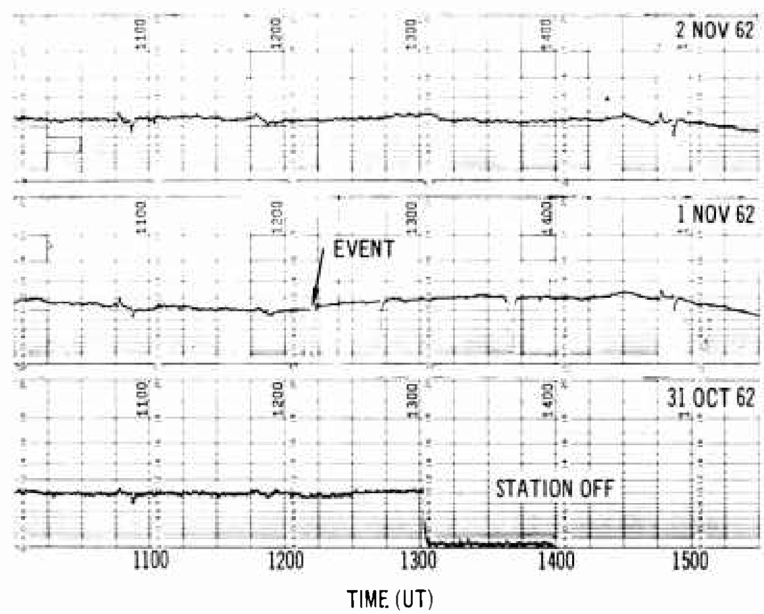

Figure 11. Field intensity recording of 10.2-kc/s transmissions from Haiku, Hawaii, taken at Whidbey Is., Wash., 31 October and 1-2 November 1962. Time constant, 5 sec; calibration: add 35 for dB above 1 μV/meter; receiver, NEL field intensity meter and AN/URN-18(XN-1).

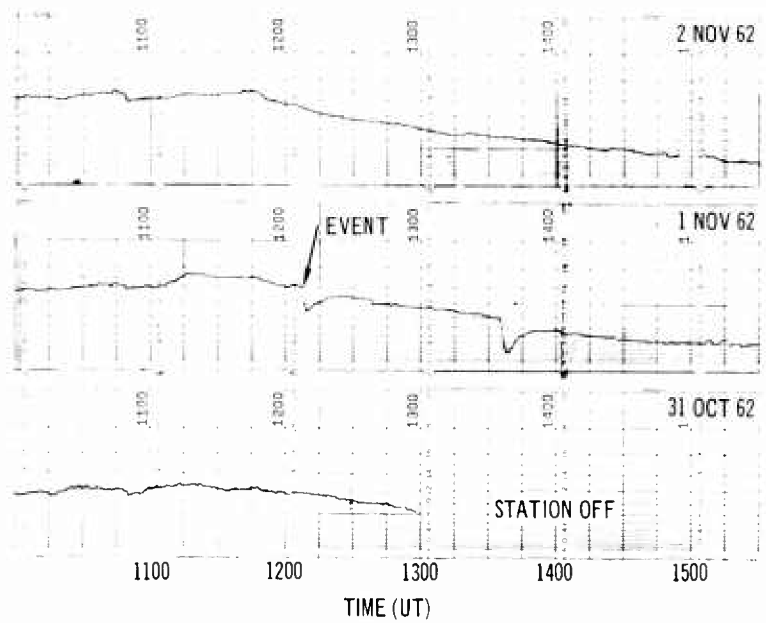

Figure 12. Field intensity recording of 10.2-kc/s transmissions from Haiku, Hawaii, taken at Rome, N.Y., 31 October and 1-2 November 1962. Time constant, 5 sec; calibration: add 25 for dB above 1 μV/meter; receiver, NEL field intensity meter and AN/URN-18(XN-1).

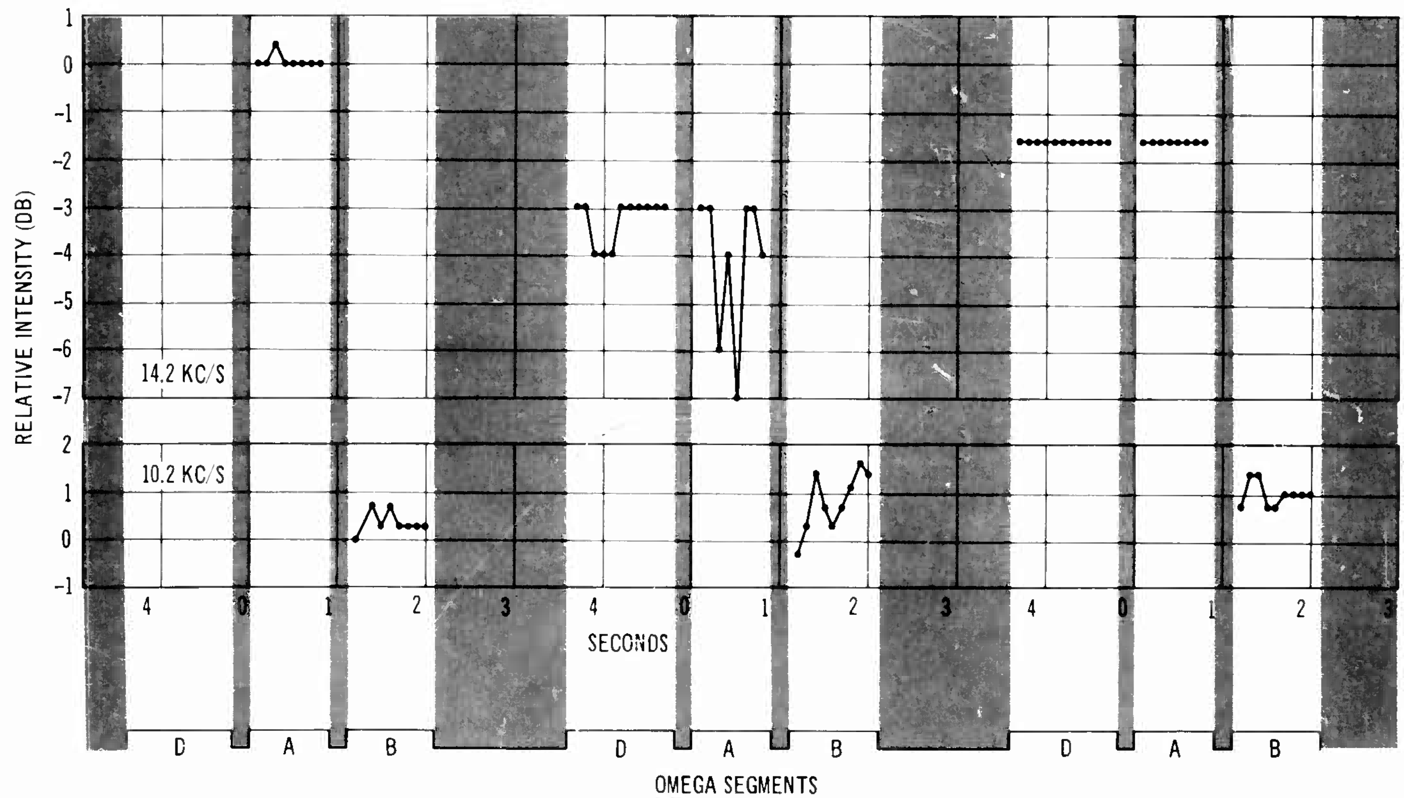

Figure 13. Intensity measurements of 10.2 and 14.2 kc/s transmissions from Haiku, Hawaii, taken at NEL, San Diego, 1 November 1962, as plotted from constant-speed, continuous-motion photographs of displays.

ONE-WAY PHASE RECORDINGS

Figure 14 illustrates one-way phase measurement between Balboa, C. Z., and Opana, Hawaii. The two-path phase measurement from Balboa, C. Z., to Haiku, Hawaii, to Rome (Forestport), N. Y., is similarly diagrammed in figure 15. Figures 16-31 (reproduced from original traces) indicate the changes in "one-way" propagation time from the master station to the monitoring station, plus any relative frequency difference or oscillator drift. (See table 5.) The measurements were made by equipment using the conventional mechanical servo phase-tracking method, which shows the change in phase of the received carrier in relation to the phase of a local high-stability oscillator.

In all the phase recordings, the travel of the recorded line across the full width of the chart represents a change in phase of 360 degrees, or 98 microseconds. An increase in value on the chart (a decrease on fig. 28 only) represents an increase in transmission time of the distant signal. Figures 24 and 30 are the phase recordings taken from constant-speed, continuous-motion photographs (film speed, 30 in./sec).

Figures 25 and 31 are recordings of the phase of Omega transmissions from Haiku, Hawaii, and indicate change in "one-way" propagation from master station to the monitoring station. This signal was recorded on magnetic tape and the signal "played back" later to the NEL synchronizer for this record.

Figures 20 and 21 are the same as the data shown in figures 16 and 18 except that they show three complete days to give a better over-all picture of day-to-night phase changes, both preceding and following the event.

It will be noted on the phase recordings of 10.2-kc/s transmissions that the stations themselves program regularly spaced offsets or "signatures" that are 10 microseconds in amplitude and last for 6 minutes. The times at which these signatures occurred for each event are listed below:

Signature Times (UT) for Event STARFISH (9 July 1962)

Haiku	2315	0315	0715	1115	1515	1915
Balboa	0015	0415	0815	1215	1615	2015
Forestport	0115	0515	0915	1315	1715	2115

Signature Times (UT) for Events BLUEGILL (26 October 1962) and KINGFISH (1 November 1962)

Haiku	2245	0245	0645	1045	1445	1845
Balboa	2345	0345	0745	1145	1545	1945
Forestport	0045	0445	0845	1245	1645	2045

It will also be noted that the slave stations reflect the signature of the master station, as well as their own signatures.

There are no signatures in the 14.2-kc/s transmissions.

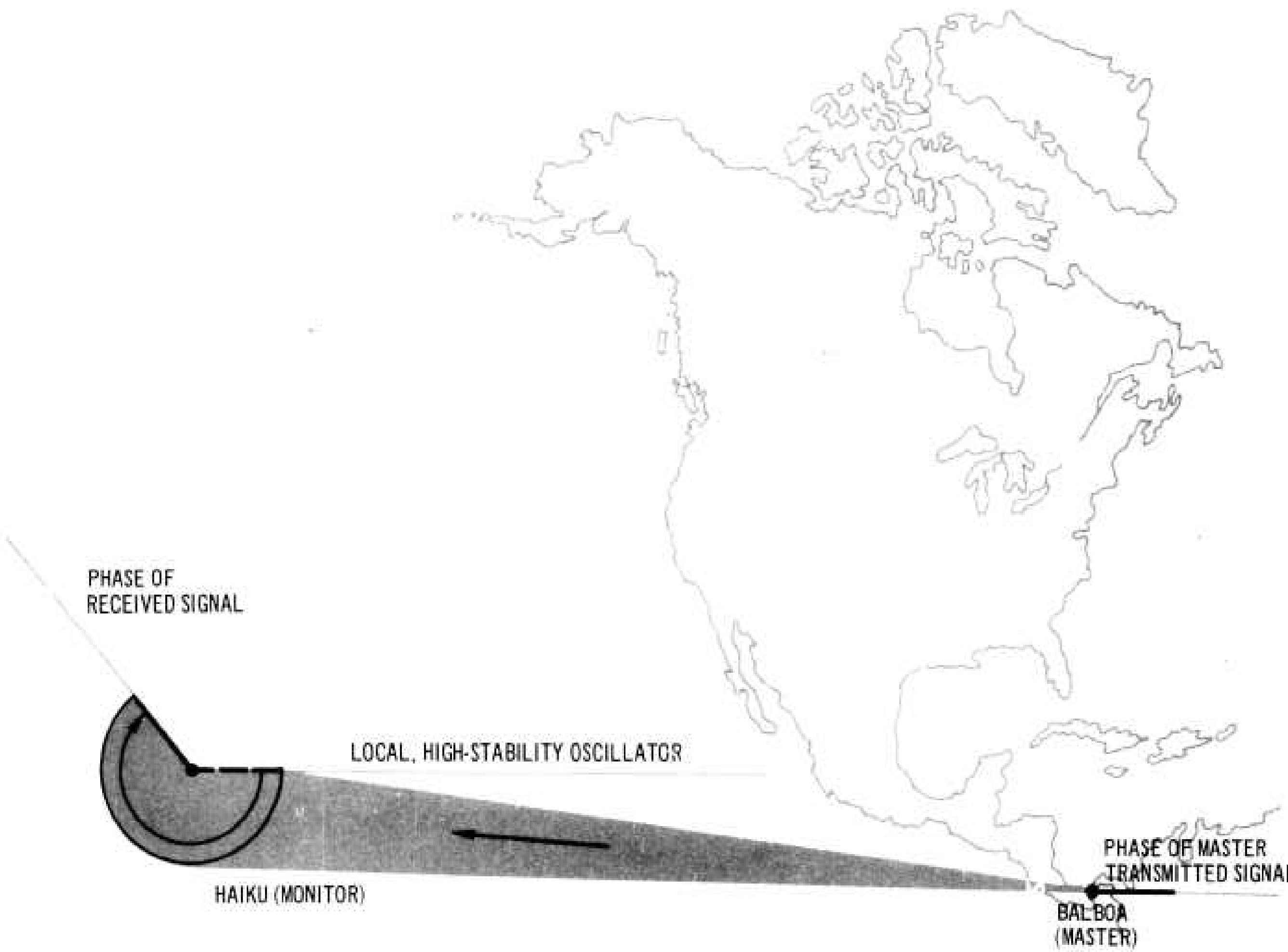

Figure 14. Illustration of one-way phase measurement between Balboa, C.Z., and Haiku, Hawaii. The signal is transmitted from Balboa, the master station, and received at some later time at Haiku. For simplicity the phase of the transmitted signal at Balboa and that of the local oscillator at Haiku are shown as the same. Phase difference recordings will indicate variations in time of travel from Balboa to Haiku, plus any phase variations of the local oscillator with respect to the master oscillator.

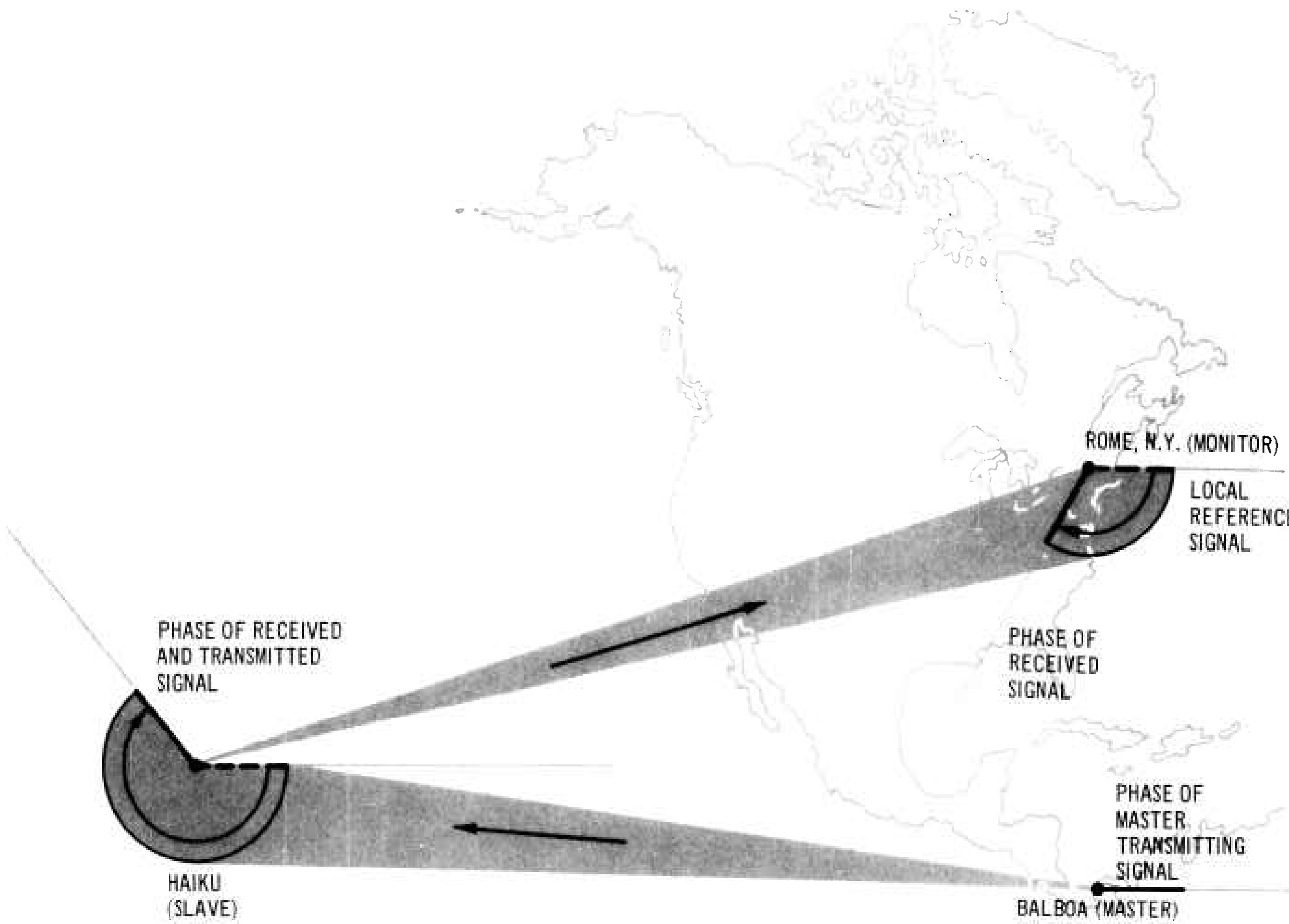

Figure 15. Illustration of two-path phase recordings from Balboa, C.Z., to Haiku, Hawaii, to Rome (Forestport), N.Y. The 10.2-kc/s signal is transmitted from Balboa, the master station, and received at some later time at Haiku. The phase of the Haiku transmissions is then synchronized with the received signal from Balboa. The signal as received at Rome is then compared with a local high-stability oscillator. Phase difference recordings will indicate variations in time of travel from Balboa to Haiku, as well as between Haiku and Rome. Any drift of the local oscillator with respect to the master oscillator will also show in these recordings.

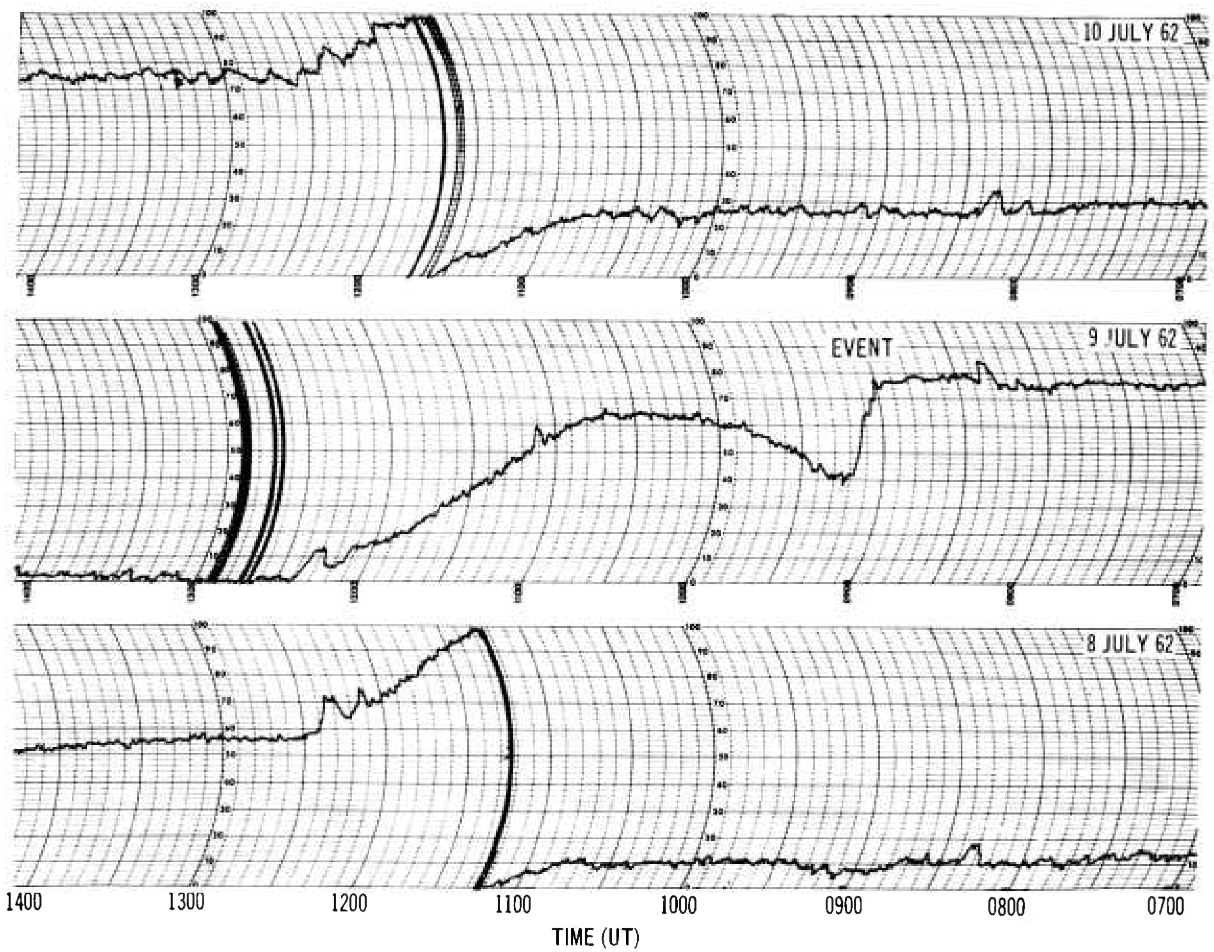

Figure 16. Phase of 10.2-kc/s transmissions from Balboa, C.Z., as recorded at NEL, San Diego, 8, 9, 10 July 1962. Scale, 1 cycle full scale; time scale, 6 min./division; receiver, NEL synchronizer (master phase channel). Very little oscillator drift is indicated here and in fig. 18, since these recordings were made at fixed permanent sites where stable frequency standards were available.

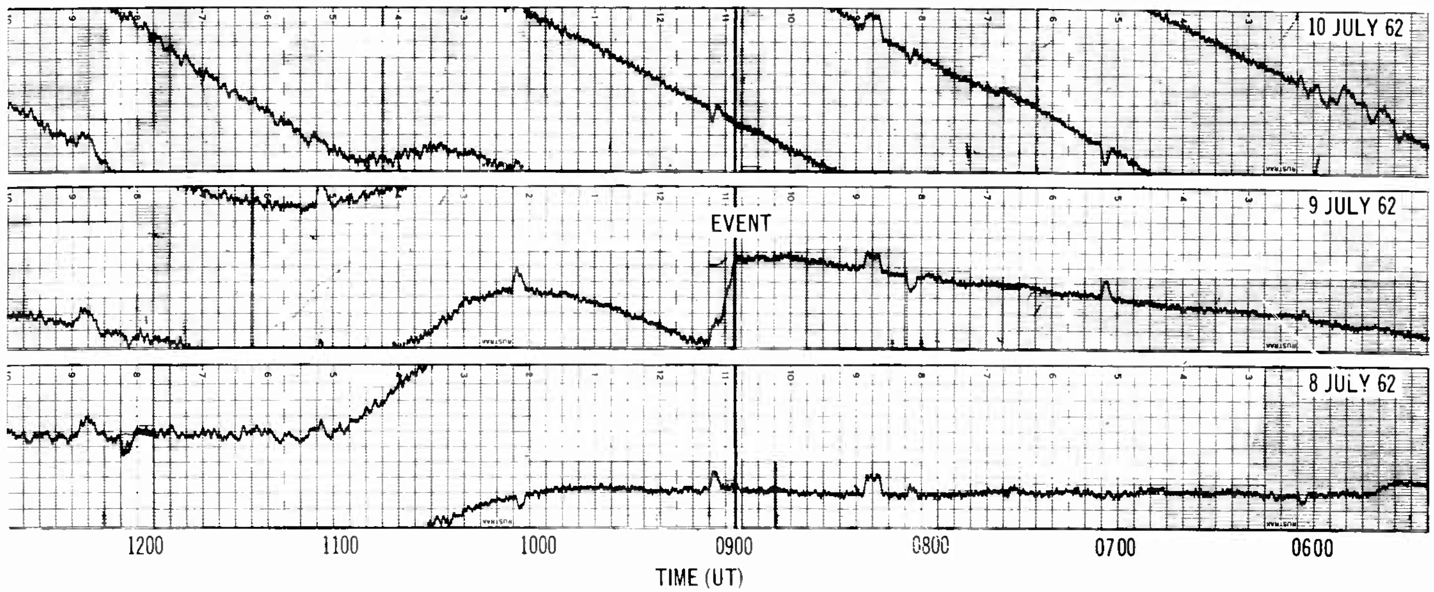

Figure 17. Phase of 10.2-kc/s transmissions from Balboa, C.Z., as recorded at Pt. Barrow, Alaska, 8, 9, 10 July 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1) (master phase channel). The long-term instability indicated here and in fig. 19 is due to the use of reference oscillators of lower stability at remote monitoring sites.

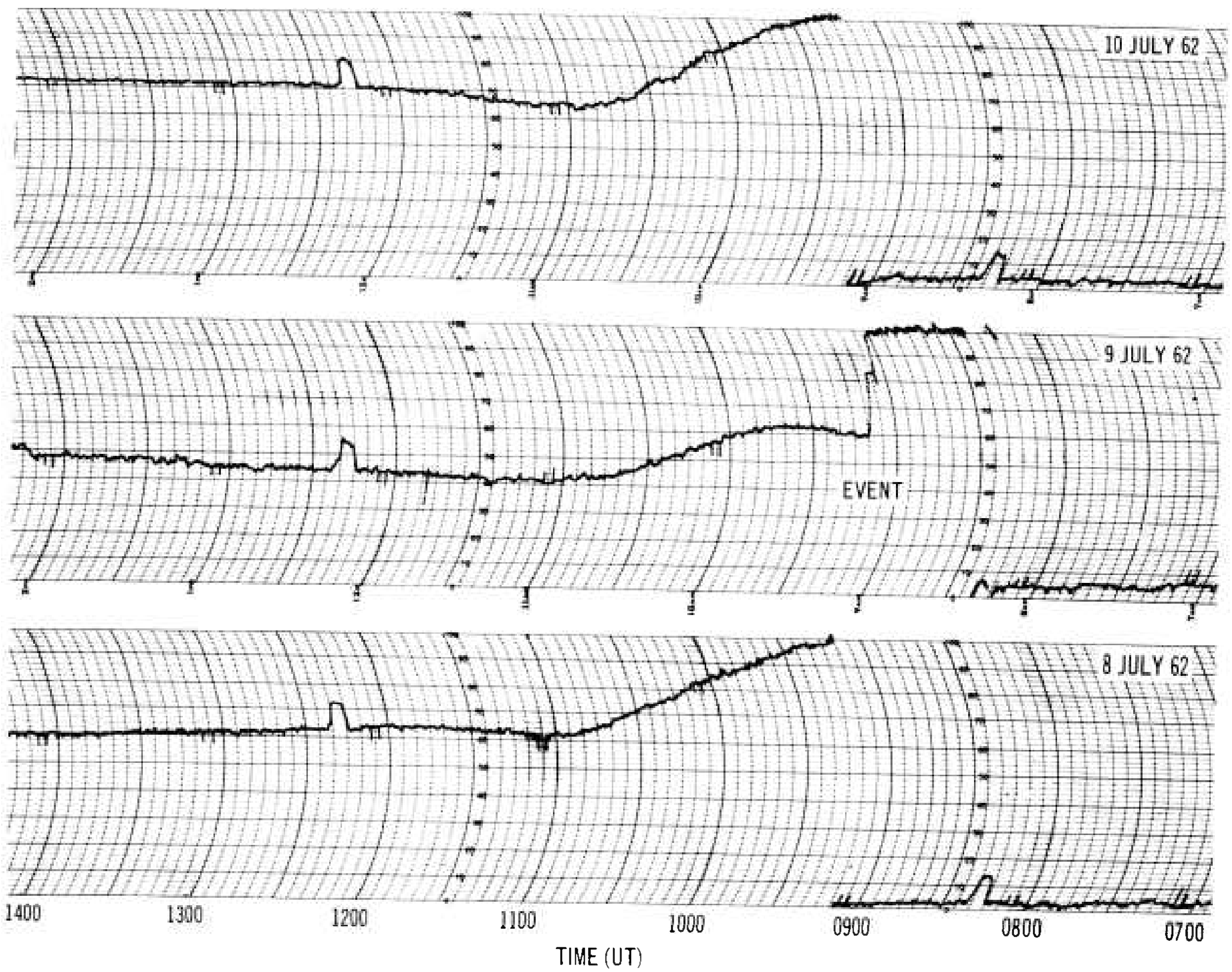

Figure 18. Phase of 10.2-kc/s transmissions from Balboa, C.Z., as recorded at Forestport, N.Y., 8, 9, 10 July 1962. Scale, 1 cycle full scale; receiver, NEL synchronizer (master phase channel). Increase in value represents increase in transmission time of the distant signal. Very little oscillator drift is indicated here and in fig. 16, since these recordings were made at fixed, permanent sites where stable frequency standards were available.

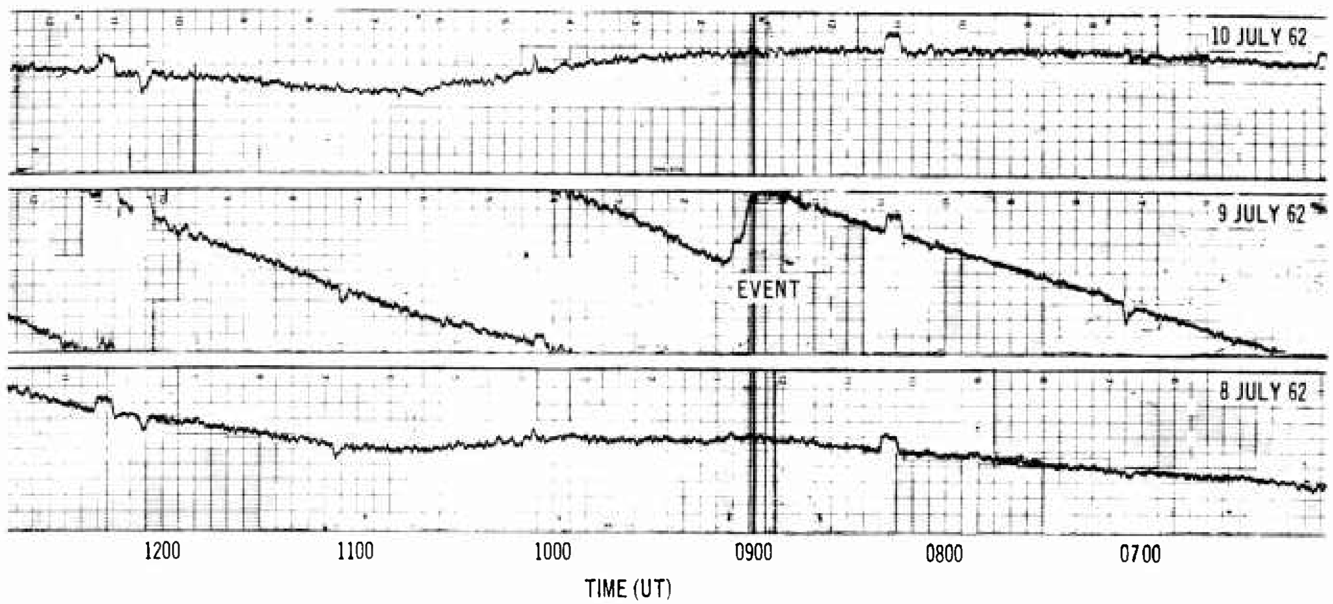

Figure 19. Phase of 10.2-kc/s transmissions from Balboa, C.Z., as recorded at Thule, Greenland, 8, 9, 10 July 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1) (master phase channel). The long-term instability indicated here and in fig. 17 is due to the use of reference oscillators of lower stability at remote monitoring sites.

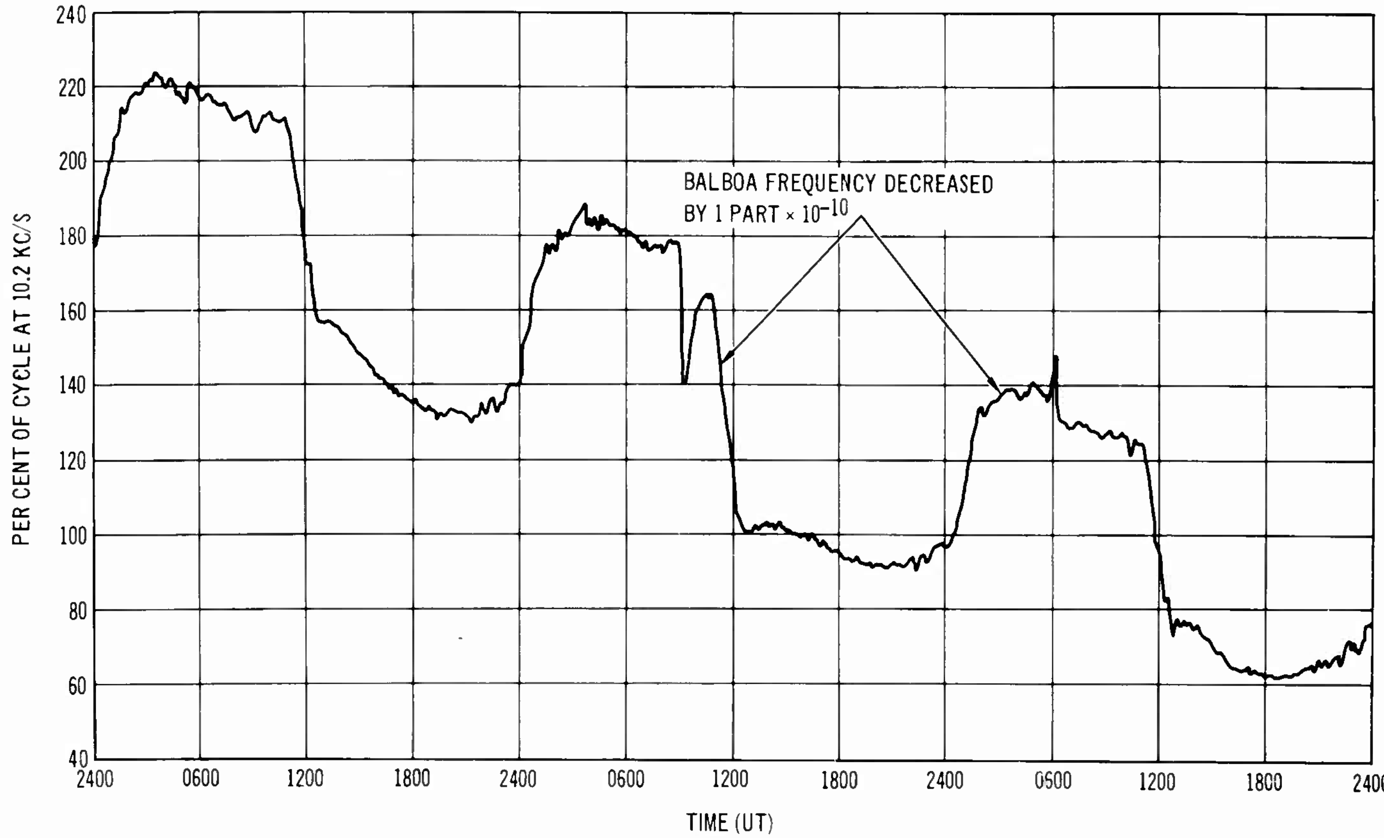

Figure 20. One-way phase of 10.2-kc/s Omega transmissions from Balboa, C.Z., as recorded at NEL, San Diego, 8, 9, 10 July 1962. The data are the same as shown in fig. 16, except that they cover three complete days to give a better over-all picture of day-to-night phase changes, both preceding and following the event.

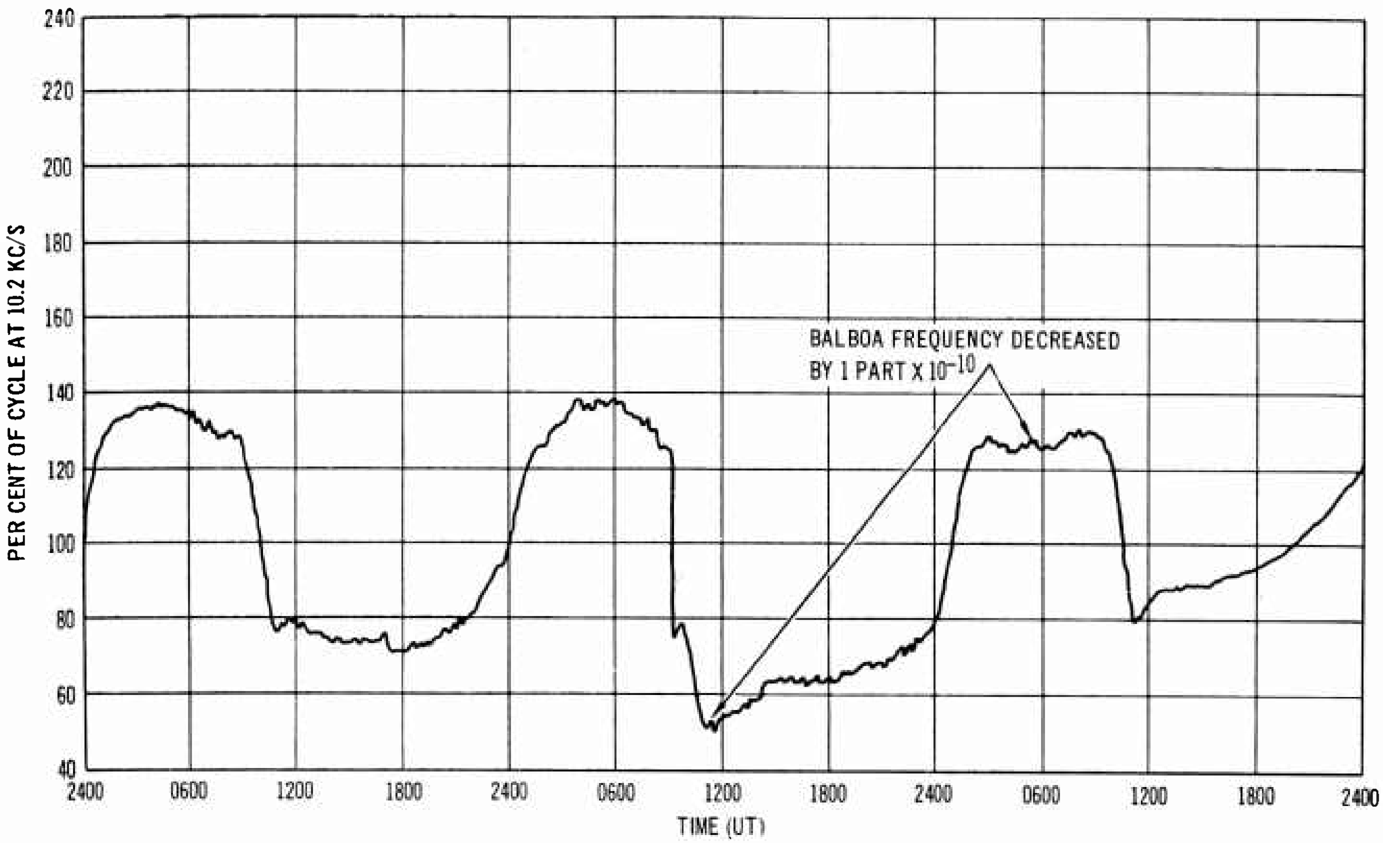

Figure 21. One-way phase of 10.2-kc/s transmissions from Balboa, C.Z., as recorded at Forestport, N.Y., 8, 9, 10 July 1962. The data are the same as shown in fig. 18, except that they cover three complete days to give a better over-all picture of day-to-night phase changes, both preceding and following the event.

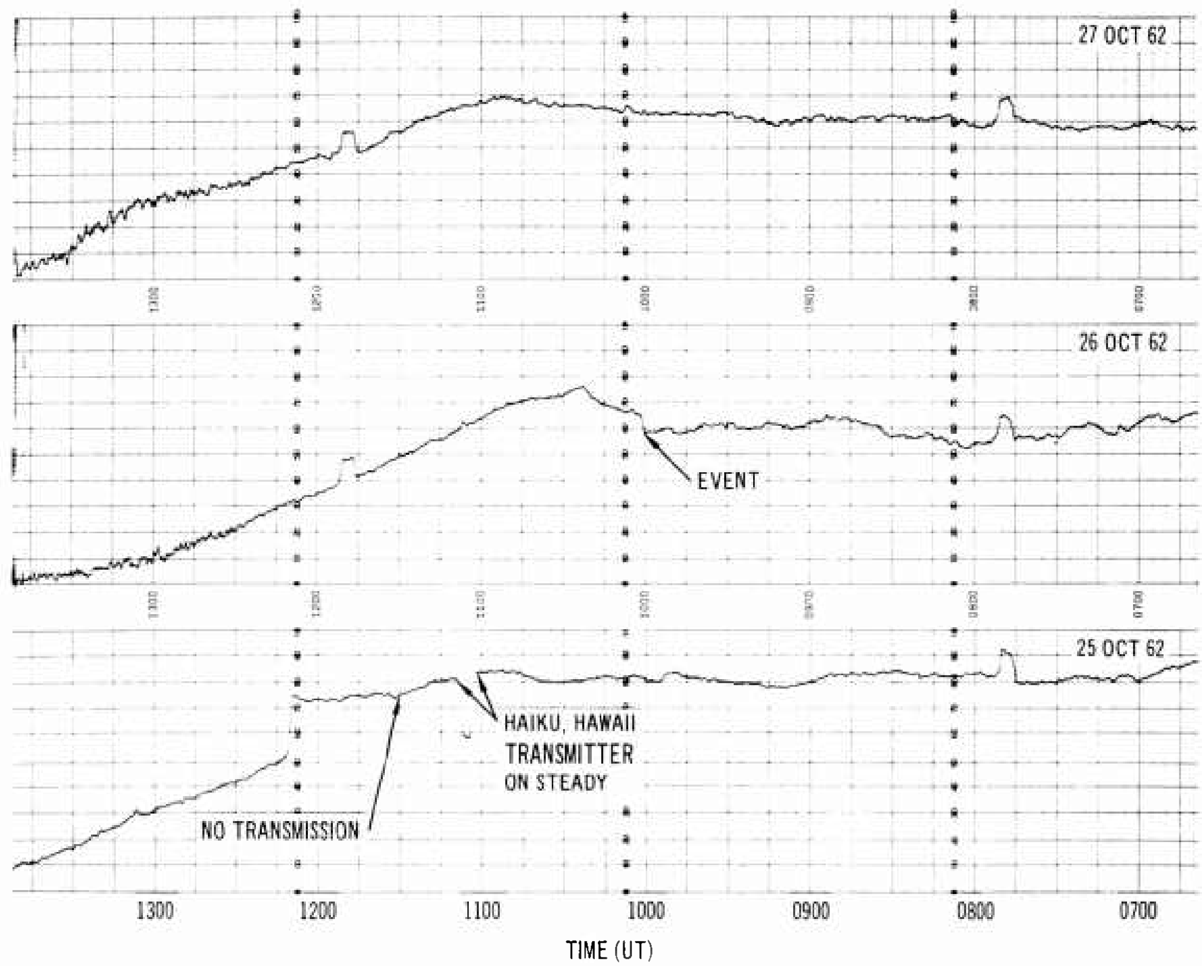

Figure 22. Phase of 10.2-kc/s transmissions from Balboa, C.Z., as recorded at Opana, Hawaii, 25, 26, 27 October 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1).

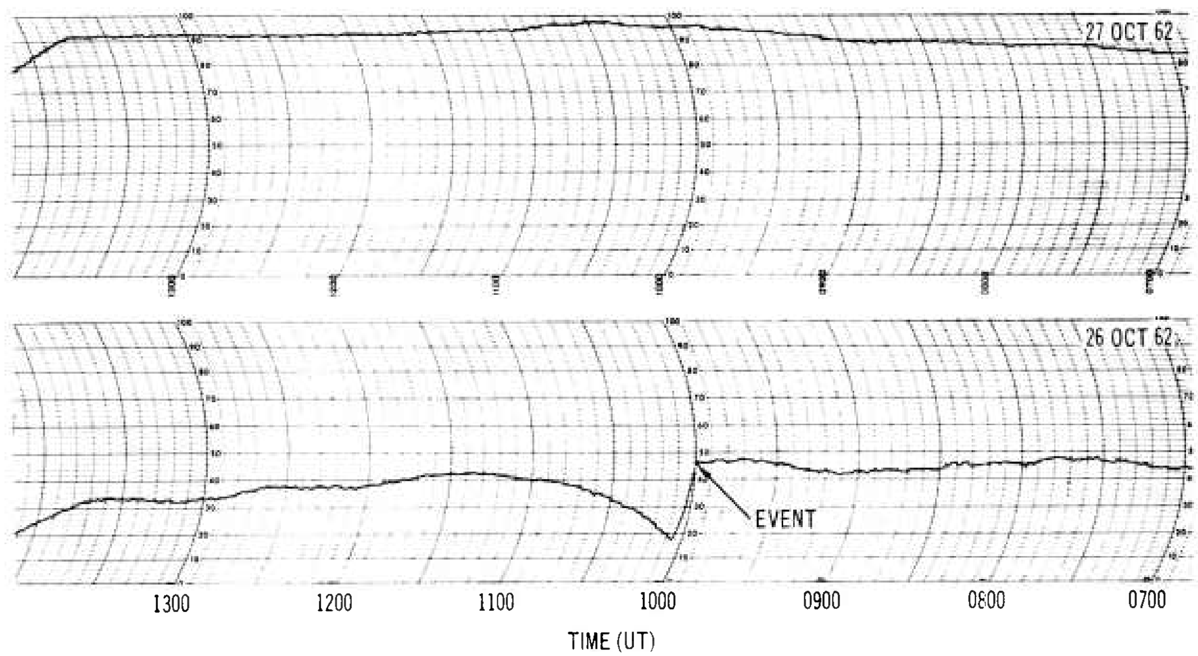

Figure 23. Phase of 14.2-kc/s transmissions from Haiku, Hawaii, as recorded at NEL, San Diego, 26-27 October 1962. Scale, 1 cycle full scale; receiver, AN/URN-17(XN-1). No data available for 25 Oct 62.

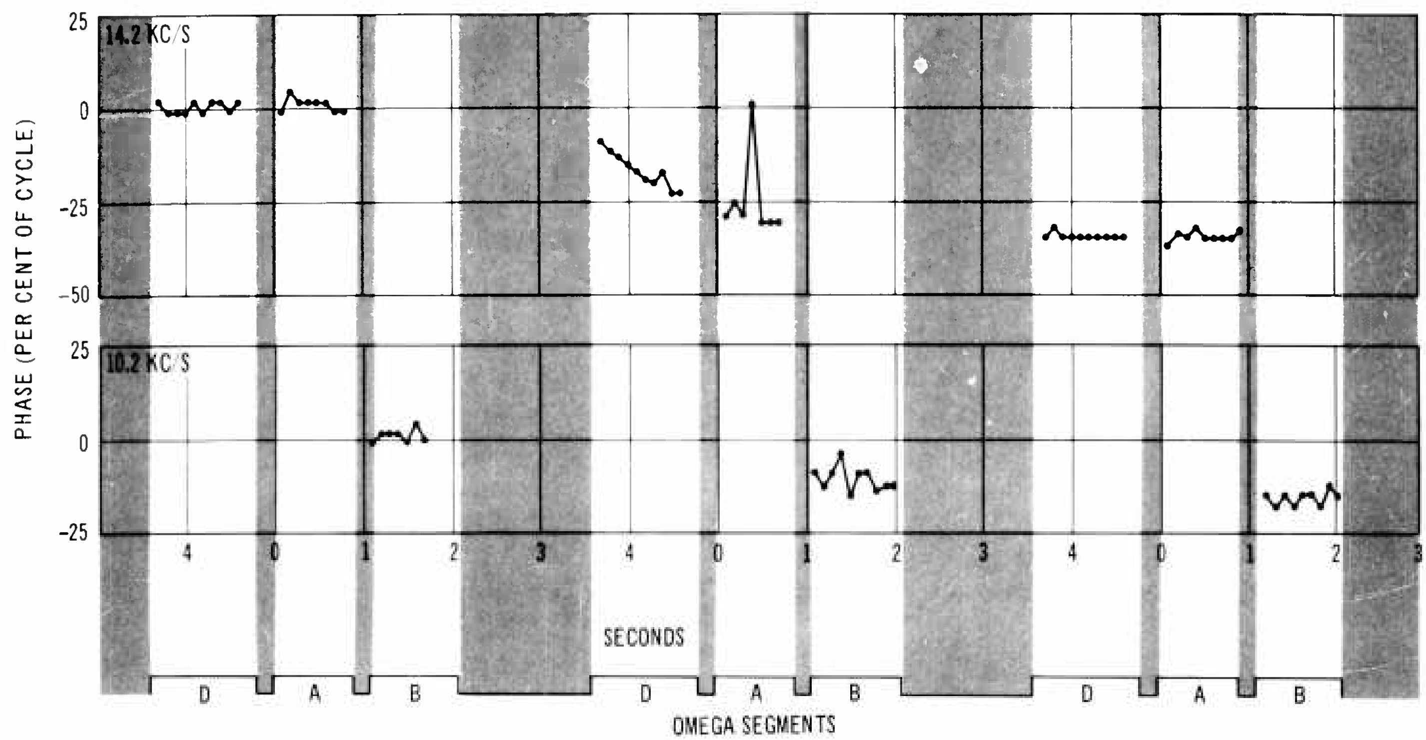

Figure 24. Phase of 10.2 and 14.2 kc/s transmissions from Haiku, Hawaii, taken at NEL, San Diego, 26 October 1962, as plotted from constant-speed, continuous-motion photographs of tape-recorded displays.

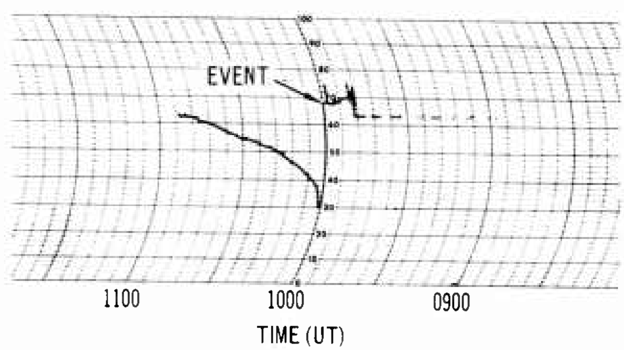

Figure 25. Phase of 14.2-kc/s transmissions from Haiku, Hawaii, as recorded at NEL, San Diego, 26 October 1962. Scale, 1 cycle full scale. The signal was recorded on magnetic tape and "played back" later to the NEL synchronizer for this record, which shows the change in one-way propagation from master to monitoring station.

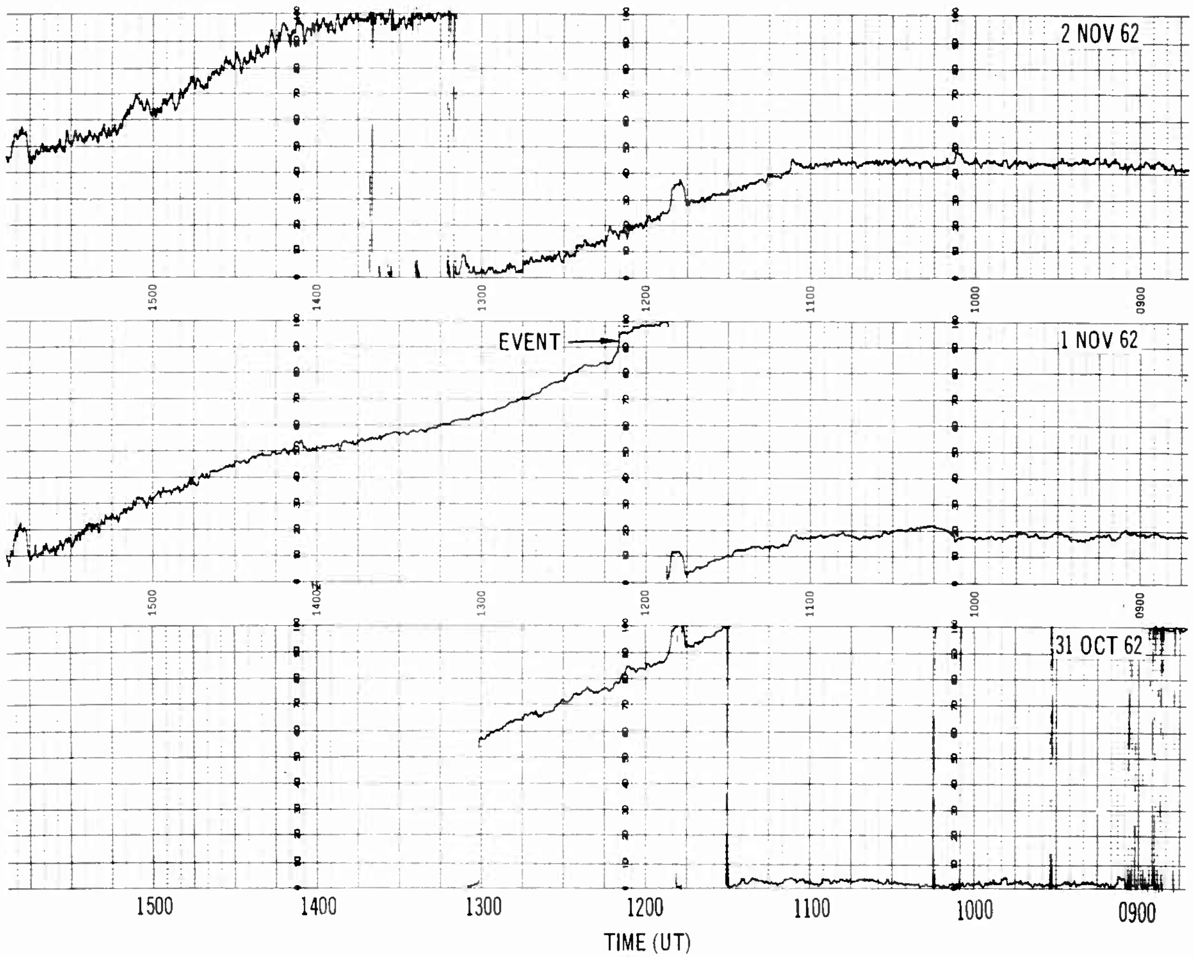

Figure 26. Phase of 10.2-kc/s transmissions from Balboa, C.Z., to Opana, Hawaii, 31 October and 1-2 November 1962. Scale, 1 cycle full scale. Receiver, AN/URN-18(XN-1). Record indicates changes in one-way propagation time from master to monitoring station plus any relative frequency difference or drift. It was made by equipment using the conventional, mechanical servo, phase-tracking method, which shows the change in phase of the received carrier in relation to the phase of a local high-stability oscillator. Increase in value represents an increase in transmission time of the distant signal.

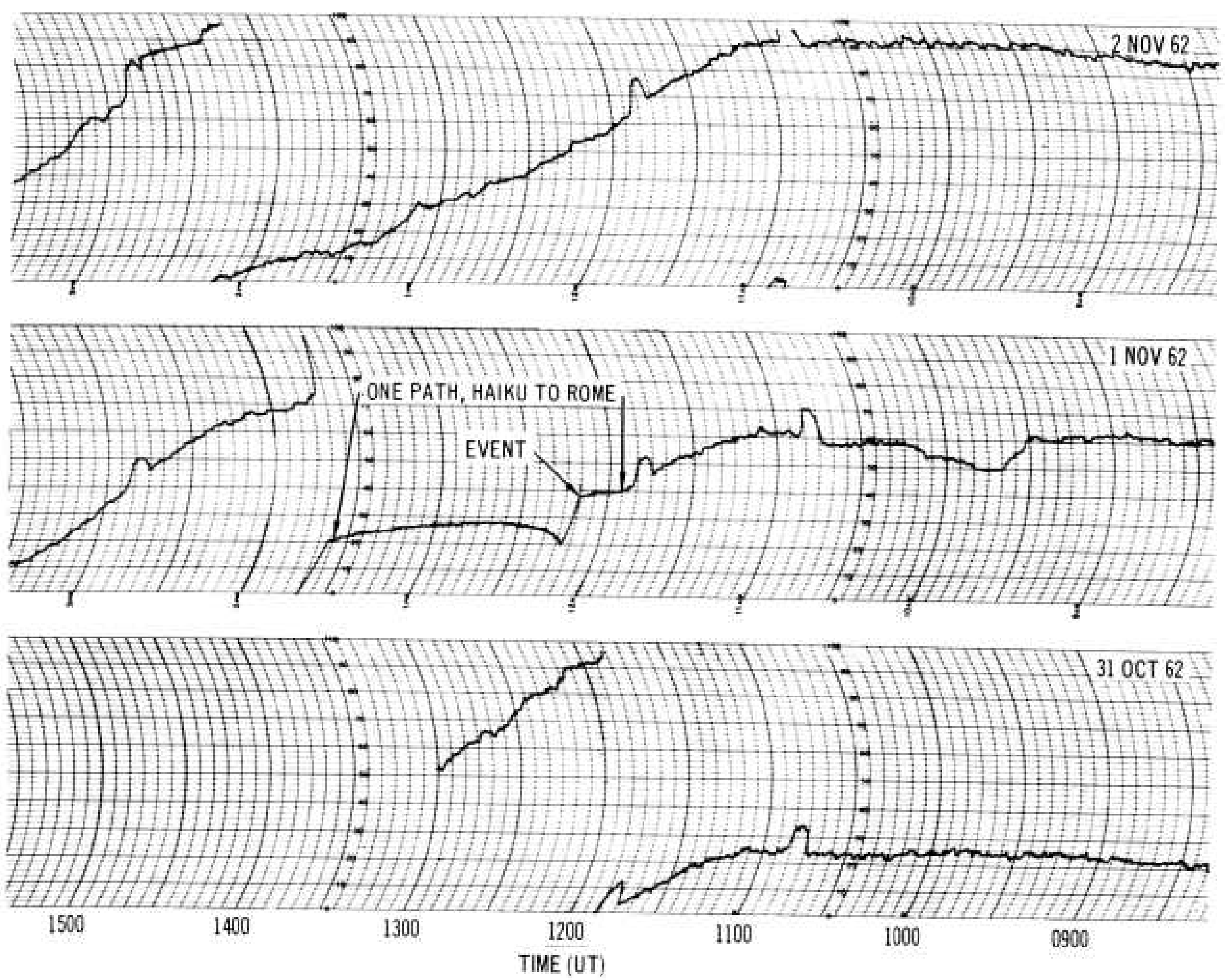

Figure 27. Phase of 10.2-kc/s transmissions from Haiku, Hawaii, as recorded at Rome, N.Y., 31 October and 1-2 November 1962, including sum of propagation effects over two paths (Balboa to Haiku and Haiku to Rome). Scale, 1 cycle full scale; receiver, Forestport synchronizer. Effects of oscillator drift at Haiku have been removed from the recordings by the action of the Omega synchronizer servo system, which holds the transmitted phase at the Haiku station equal to the incoming phase from Balboa. The Haiku master servo was turned off for a 1-hour period during the event.

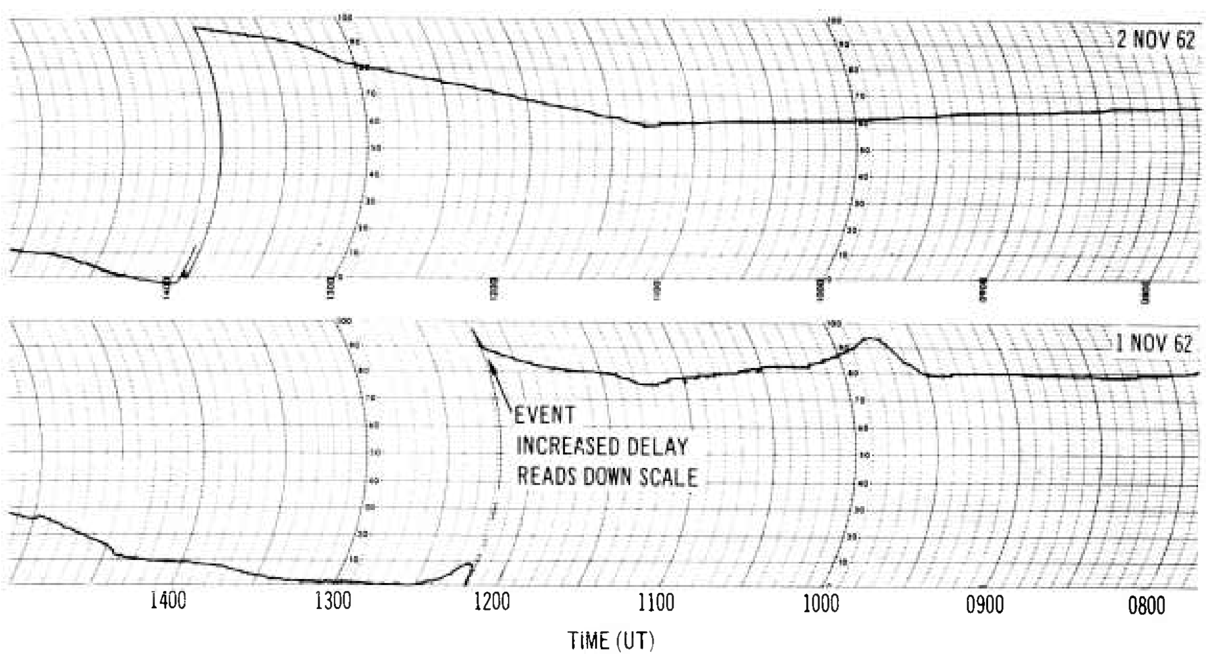

Figure 28. Phase of 14.2-kc/s transmissions from Haiku, Hawaii, as recorded at Rome, N.Y., 1-2 November 1962. Scale, 1 cycle full scale; receiver, NEL prototype. Record indicates changes in one-way propagation time from master to monitoring station plus any relative frequency difference or drift. It was made by equipment using the conventional, mechanical servo, phase-tracking method, which shows the change in phase of the received carrier in relation to the phase of a local high-stability oscillator. Decrease in value represents an increase in transmission time of the distant signal. (Note: This is shown with inverted sense with respect to other recordings.) No data available for 31 Oct 62.

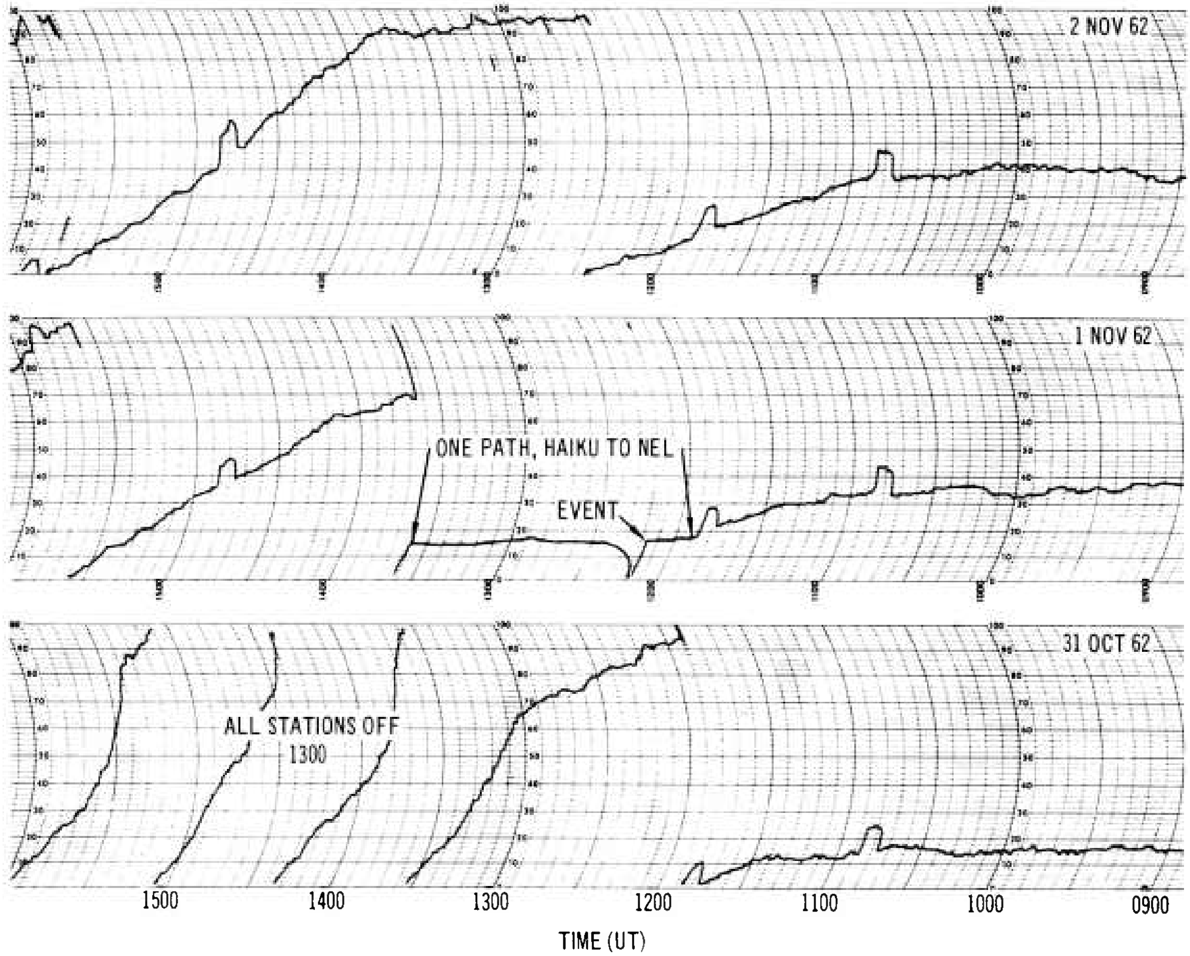

Figure 29. Phase of 10.2-kc/s transmissions from Haiku, Hawaii, as recorded at NEL, 31 October and 1-2 November 1962, including sum of propagation effects over two paths (Balboa to Haiku and Haiku to NEL). Scale, 1 cycle full scale; receiver, NEL synchronizer. Effects of oscillator drift at Haiku have been removed from the recordings by the action of the Omega synchronizer servo system, which holds the transmitted phase at the Haiku station equal to the incoming phase from Balboa. The Haiku master servo was turned off for a 1-hour period during the event.

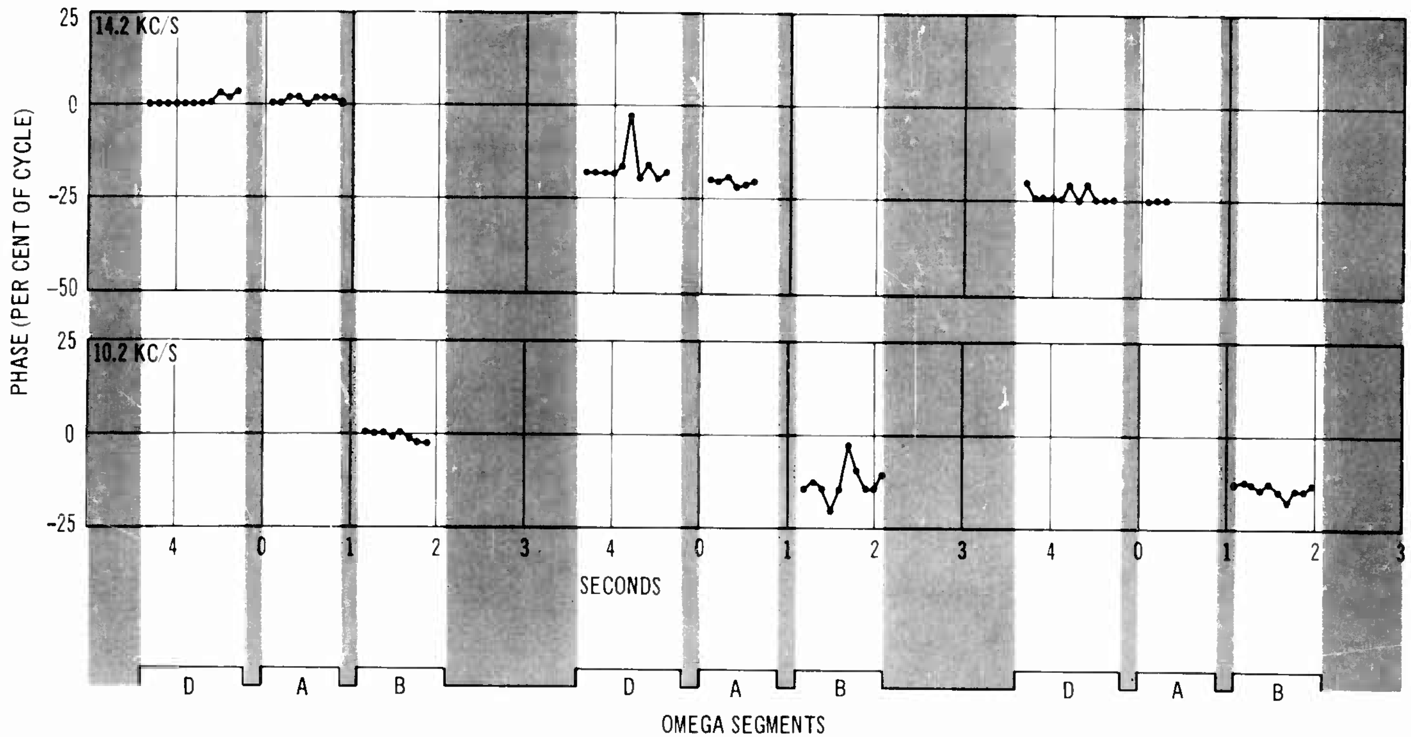

Figure 30. Phase of 10.2 and 14.2 kc s transmissions from Haiku, Hawaii, measured at NEL, San Diego, 1 November 1962, as plotted from constant-speed, continuous-motion photographs of tape-recorded displays (film speed, 30 in. sec).

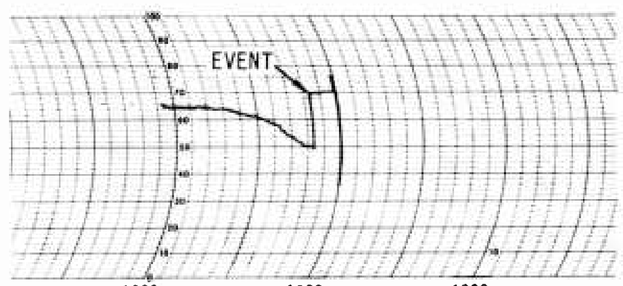

Figure 31. Phase of 14.2-kc/s transmissions from Haiku, Hawaii, as measured at NEL, San Diego, 1 November 1962. Scale, 1 cycle full scale. The signal was recorded on magnetic tape and "played back" later to the NEL synchronizer for this record, which shows the change in one-way propagation from master to monitoring station.

TABLE 5. SUMMARY OF DATA PRESENTED IN THE ONE-WAY AND TWO-PATH PHASE RECORDINGS

Fig. No.	Transmission Path	Length of Path (km)	Approximate Distance from Detonation to Nearest Point of Path (km)	Maximum Phase Change Recorded (μsec)	Date and Time of Maximum Phase Change (UT)
16	Balboa to NEL	4666	5526	39	090900 July 62
17	Balboa to Pt. Barrow	8595	5893	55	090900 July 62
18	Balboa to Forestport	3836	9118	39	090900 July 62
19	Balboa to Thule	7681	9896	40	090900 July 62
22	Balboa to Opana	8452	1357	8	261000 Oct 62
23	Haiku to NEL	4188	1357	26	261000 Oct 62
25	Haiku to NEL	4188	1357	37	261000 Oct 62
26	Balboa to Opana	8452	1357	12	011210 Nov 62
27	Haiku to Rome, N. Y.*	7813	1357	18	011210 Nov 62
28	Haiku to Rome, N. Y.	7813	1357	16	011209 Nov 62
29	Haiku to NEL*	4188	1357	17	011209 Nov 62
31	Haiku to NEL	4188	1357	20	011208 Nov 62
32	Balboa to Forestport to NEL	7676	5526		090900 July 62
34	Haiku to Forestport*	7835	1357	17	261000 Oct 62
35	Haiku to NEL*	4188	1357	18	261000 Oct 62

*See figure caption for special conditions.

TWO-PATH PHASE RECORDINGS*

Figures 27, 29, 32-35 are one-way phase recordings that include the sum of the propagation effects over two paths. Any drift of the local oscillator with respect to the master station oscillator will show in these recordings. During Events BLUEGILL and KINGFISH (figs. 27, 29, 34, and 35), the Haiku master servo was turned off for a 1-hour period straddling the event. During this period, phase recordings taken at Rome and NEL of the Haiku transmissions include effects of the single propagation path from Haiku.

Figures 32 and 33 are phase recordings which include the sum of the propagation effects over two paths (fig. 15) (Panama to Forestport and Forestport to NEL) plus the oscillator drifts which are present between the oscillator at Panama and the one at NEL. The effect of oscillator drift at Forestport has been removed from the resulting recordings by the action of the Omega synchronizer servo system which holds the transmitted phase at the Forestport station equal to the incoming phase from Panama. Figure 33 is a three-day continuous recording of the same conditions as shown in figure 32, to show the normal day-to-night pattern of phase change.

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*See table 5.

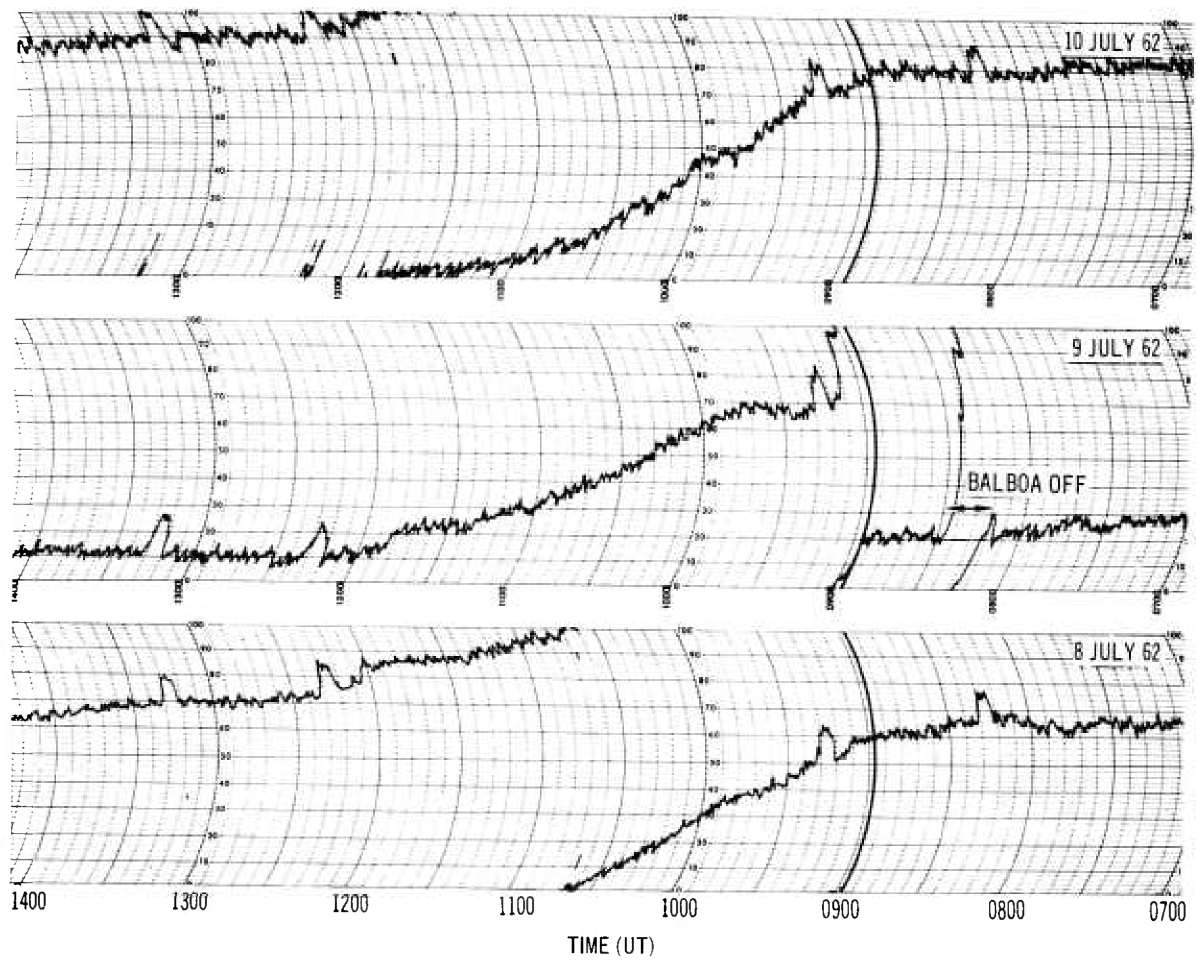

Figure 32. Phase of 10.2-kc/s transmissions from Forestport, N.Y. as recorded at NEL, San Diego, 8-10 July 1962, including sum of propagation effects over Balboa-Forestport and Forestport-NEL paths. Scale, 1 cycle full scale; receiver, NEL synchronizer.

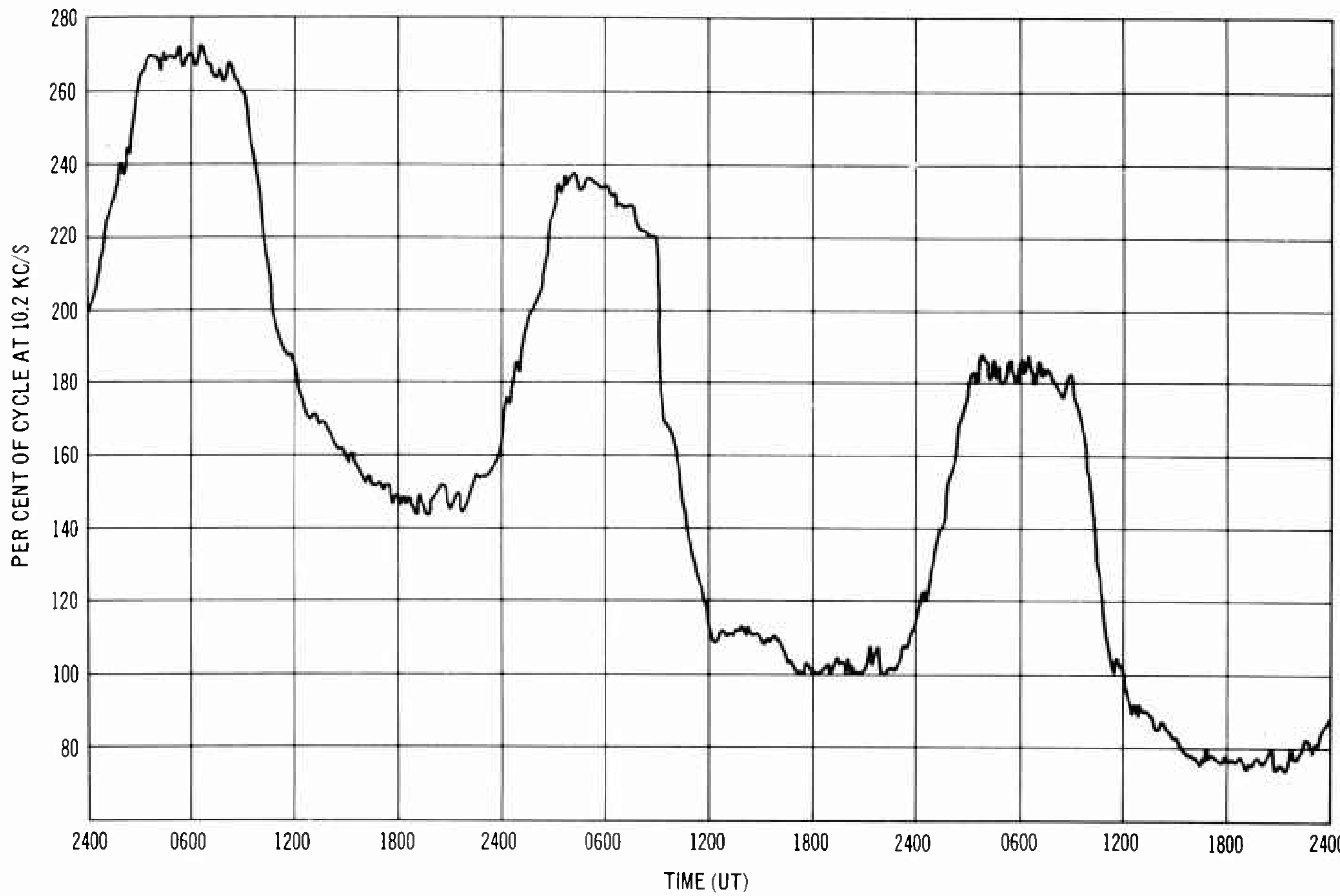

Figure 33. Data from figure 32 plotted for three complete days to illustrate normal day-to-night pattern of phase change.

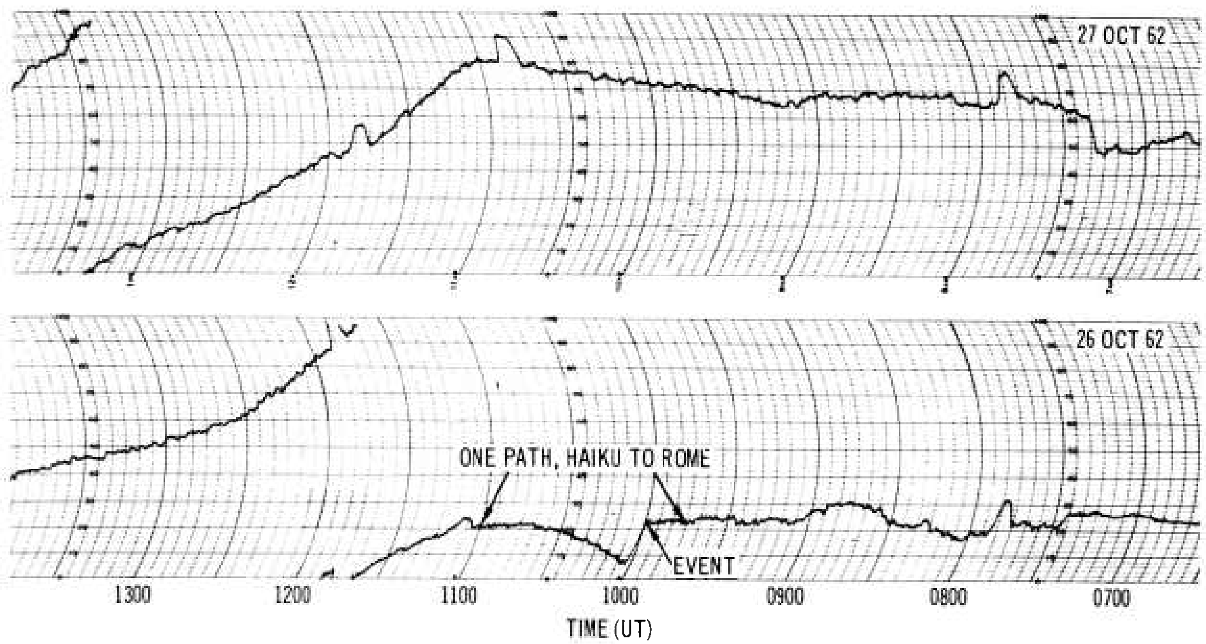

Figure 34. Phase of 10.2-kc/s transmissions from Haiku, Hawaii, as recorded at Rome, N.Y., 26-27 October 1962, including sum of propagation effects over two paths (Balboa to Haiku and Haiku to Rome). Scale, 1 cycle full scale; receiver, Forestport synchronizer. Effects of oscillator drift at Haiku have been removed from the recordings by the action of the Omega synchronizer servo system, which holds the transmitted phase at the Haiku station equal to the incoming phase from Balboa. The Haiku master servo was turned off for a 1-hour period during the event. No data available for 25 Oct 62.

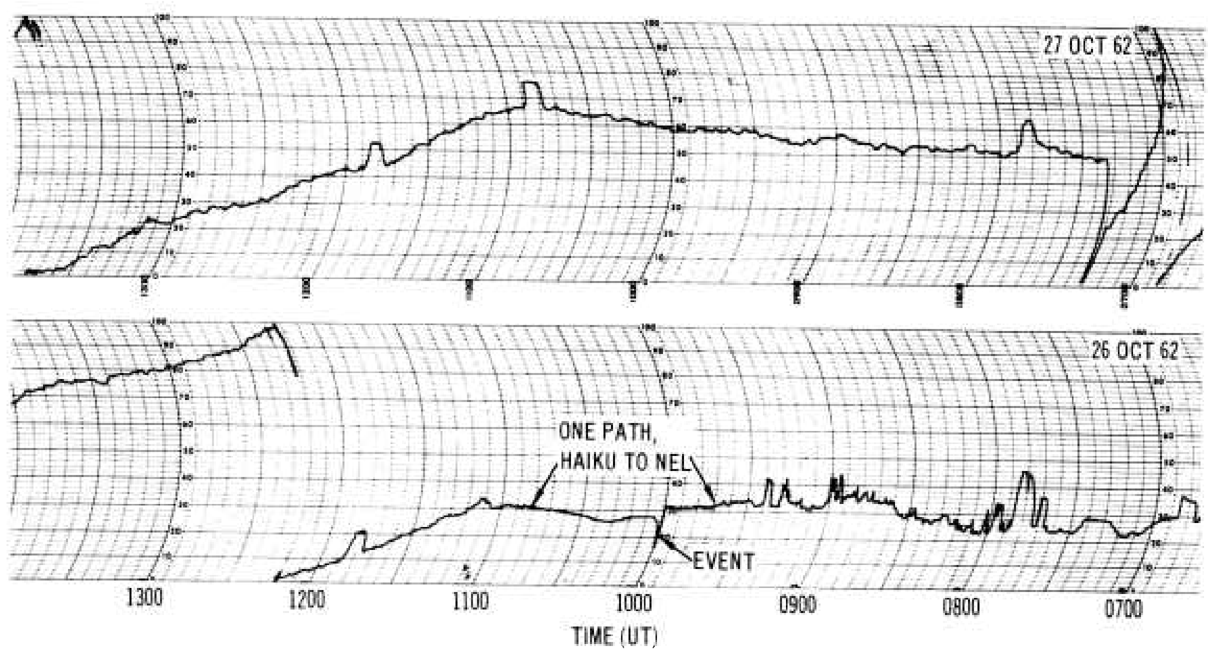

Figure 35. Phase of 10.2-kc/s transmissions from Haiku, Hawaii, as recorded at NEL, San Diego, 26-27 October 1962, including sum of propagation effects over two paths (Balboa to Haiku and Haiku to NEL), plus the oscillator drifts which are present between the oscillator at Balboa and the oscillator at NEL. The effects of oscillator drift at Haiku have been removed from the recordings by the action of the Omega synchronizer servo system, which holds the transmitted phase at the Haiku station equal to the incoming phase from Balboa. The Haiku master servo was turned off for a 1-hour period during the event, providing a record of one-path transmission as noted on the chart. Scale, 1 cycle full scale; time scale, 6 min./division; receiver, NEL synchronizer (slave phase channel). No data available for 25 Oct 62.

PHASE DIFFERENCE RECORDINGS

Figure 36 illustrates the phase difference measurement of Haiku minus Balboa measured at College, Alaska. Figures 37-52 are recordings of the phase difference between the transmissions received from the Balboa master station and the Forestport and Haiku slave stations at the various monitoring sites. (See table 6.) The recordings were made using an AN/URM-18 navigational set. The drift of the local oscillator has no effect on the results of the phase difference measurements unless it becomes excessive, and the record may be compared absolutely with the same measurement at any other time.

Figure 53 is included solely to illustrate Omega signatures and other occurrences discussed in the text which might cause confusion in studying the phase and phase difference recordings. Signatures are marked with a circle. On the phase difference recordings, the master signature is much less pronounced than the slave signature because of slave synchronization. The modified "S" curve at the beginning and end of the signature period reflects the synchronizer time lag.

During the 5th through 7th minutes of each hour, the master station at Balboa was off the air; these times are marked with a square. In some cases noise caused the slave phase to vary during these times.

The plots of phase difference data (fig. 46) for Haiku minus Balboa at Farfan, represent "round-trip" propagation from Balboa to Hawaii and back. These data were obtained from normal Omega operation and show long-term effects. Since Haiku was operating as an Omega slave except for periods near detonation, the graphs show the sum of propagation effects on the Haiku-Balboa path, east-west and west-east. As a phase difference is measured, the record is free from effects of oscillator drift and may be compared directly with the same measurement at any other time.

The "normal" standard deviations for these measurements are about 3 per cent in the daytime and 14 per cent at night.* The apparent curvature during the day is normal. Usual readings would be:

Time (UT)	Phase Difference (%)
0800	440
1730	224
1830	219
1930	216
2030	215

*An NEL Report considering details of round-trip propagation studies is in preparation.

The day-night transition is ordinarily a smooth ramp with some slight curvature toward the daytime end but without severe interference effects. Care should, however, be exercised around 1600 and also around 2330, because of abnormally poor slave phase synchronization at Haiku, possibly resulting in unreliable readings. The reason for this is the abnormally low field strength of the Balboa signals as received in Hawaii. It should be borne in mind that the autocorrelation period is long, especially in the daytime data; a displacement of several per cent from normal over several consecutive days is not unusual. Note that a 1 per cent change on the graphs represents approximately a 1 μsec variation over a 17,000 km path.

Information is included for the continuous period 26 October through 4 November 1962 for the purpose of studying long-term effects. The transmissions from Haiku were not slaved to Balboa prior to the time of the data presented in figure 46. Note also that data for the times of the events are not included because, again, the slave stations were not synchronizing on the master. In studying the records of Event KINGFISH it will be noted that recovery from BLUEGILL was not yet complete at the time of Event KINGFISH.

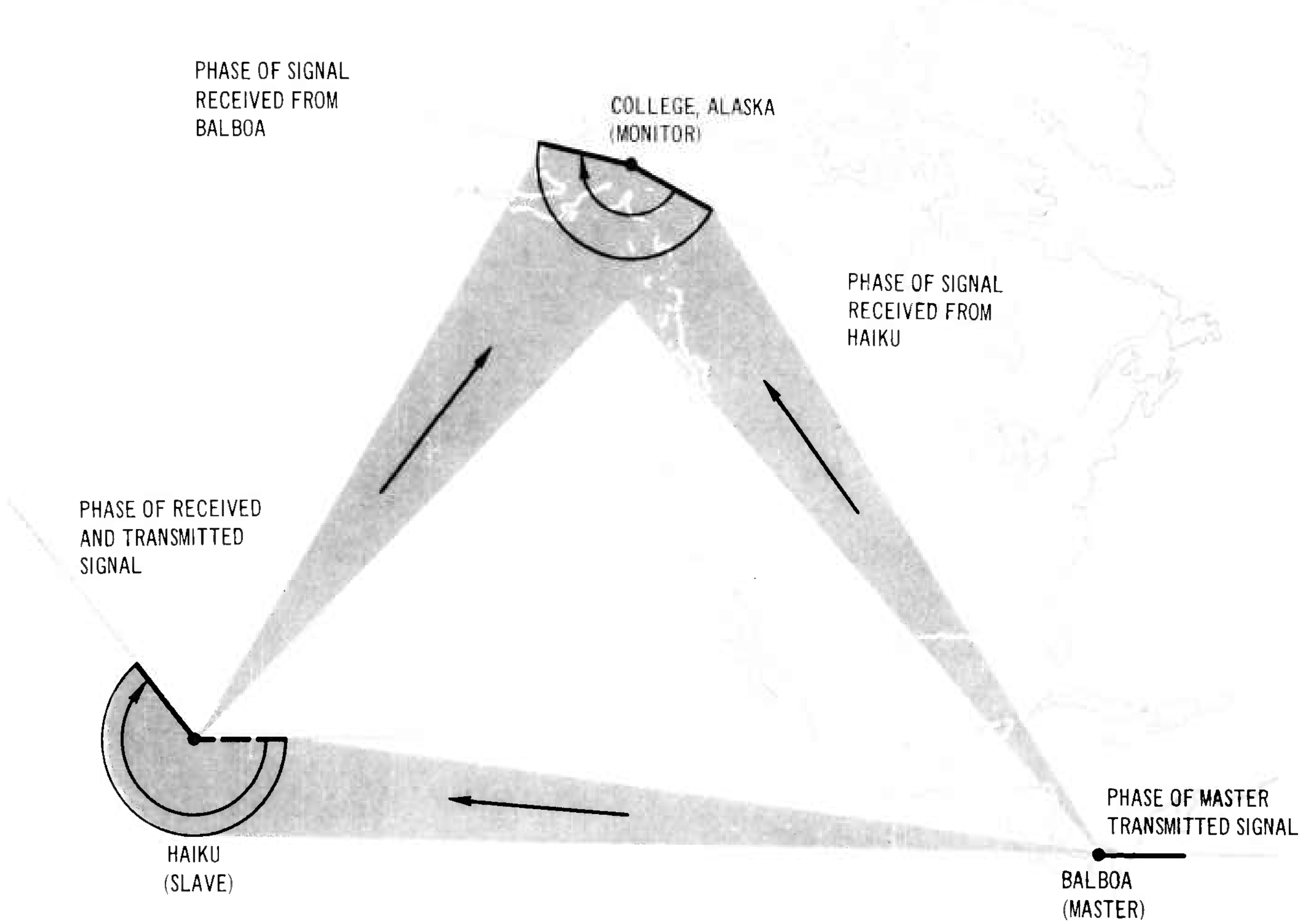

Figure 36. Illustration of phase difference recordings, Haiku minus Balboa measured at College, Alaska. The signal is transmitted from Balboa, the master station, received and retransmitted from the slave station at Haiku, and both the retransmitted slave and the master signal from Balboa are received and compared at the monitoring site (in this case College, Alaska). The resulting recording is of phase difference of the two received signals, indicated as the slave minus the master: Haiku minus Balboa.

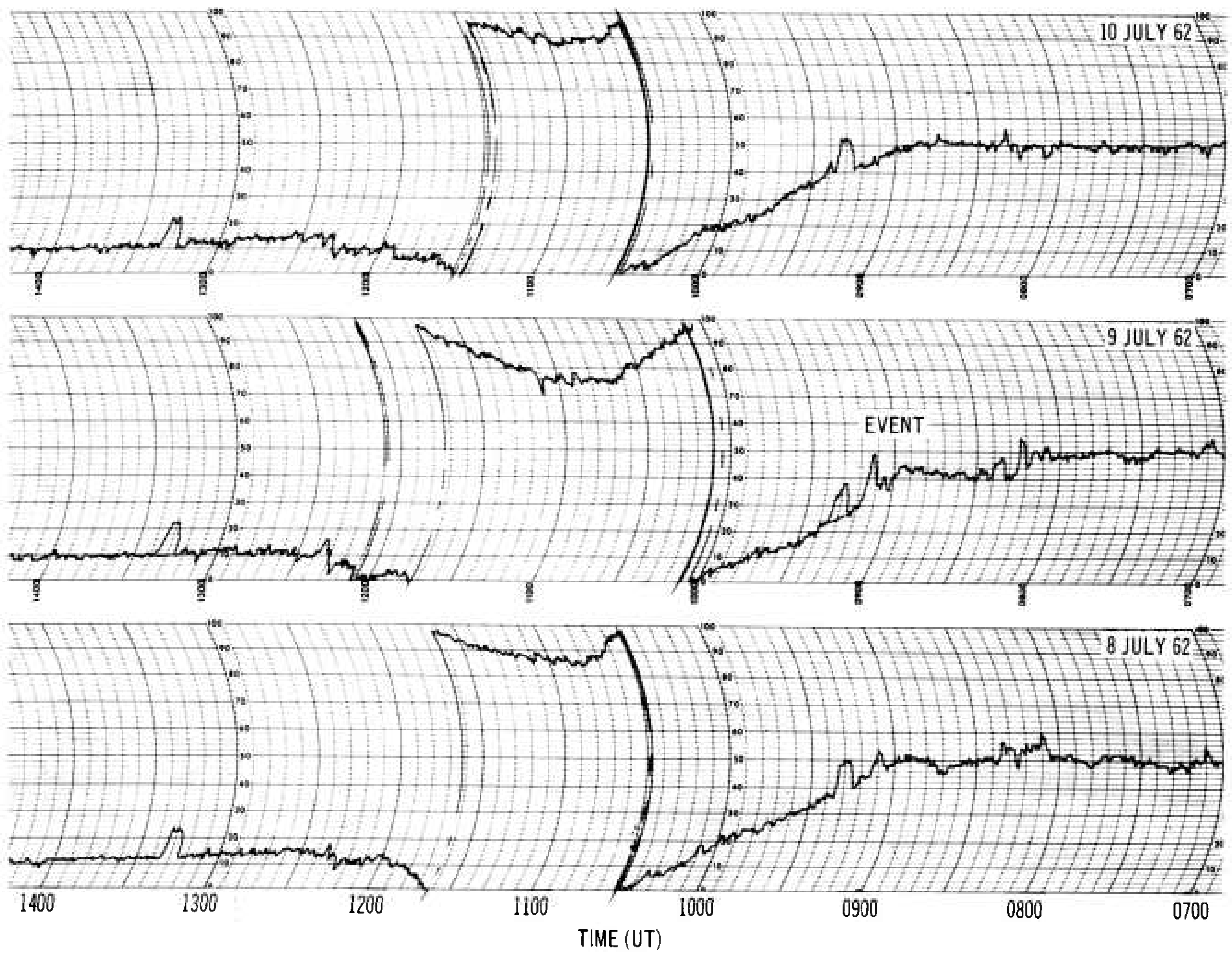

Figure 37. Phase difference between 10.2-kc/s transmissions from Forestport, N.Y., and Balboa, C.Z. (Forestport minus Balboa), recorded at NEL, San Diego, 8, 9, 10 July 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1).

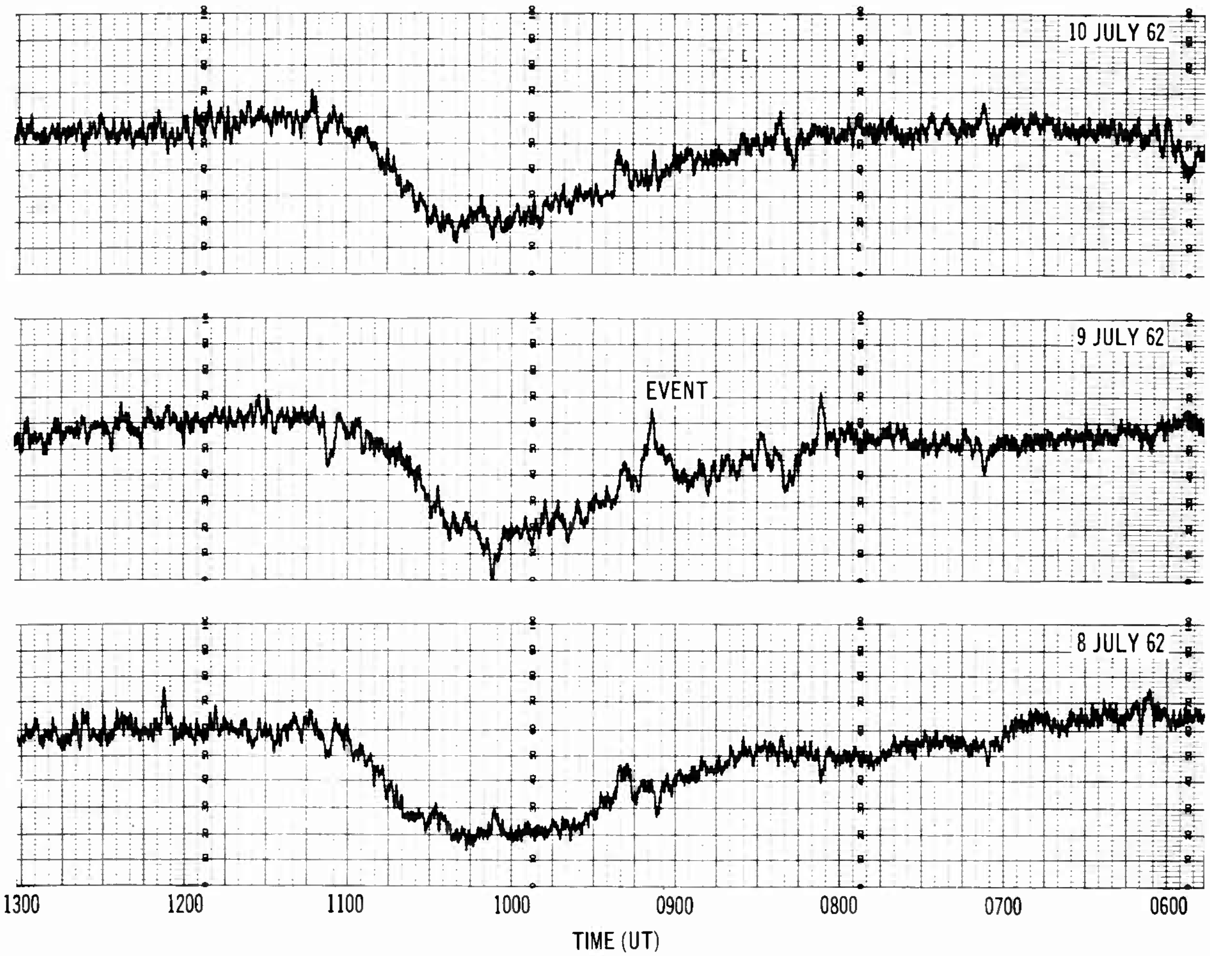

Figure 38. Phase difference between 10.2-kc/s transmissions from Forestport, N.Y., and Balboa, C.Z. (Forestport minus Balboa), recorded at Pt. Barrow, Alaska, 8, 9, 10 July 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1).

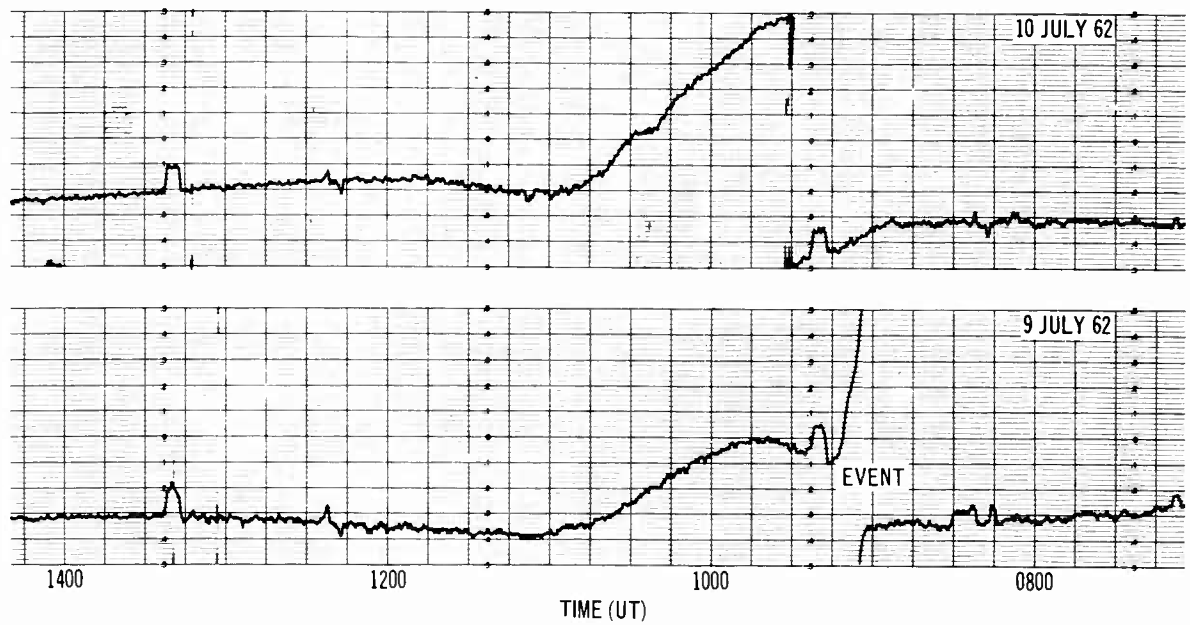

Figure 39. Phase difference between 10.2-kc/s transmissions from Forestport, N.Y., and Balboa, C.Z. (Forestport minus Balboa) recorded at Farfan, C.Z., 9-10 July 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1). No data available for 8 July 62.

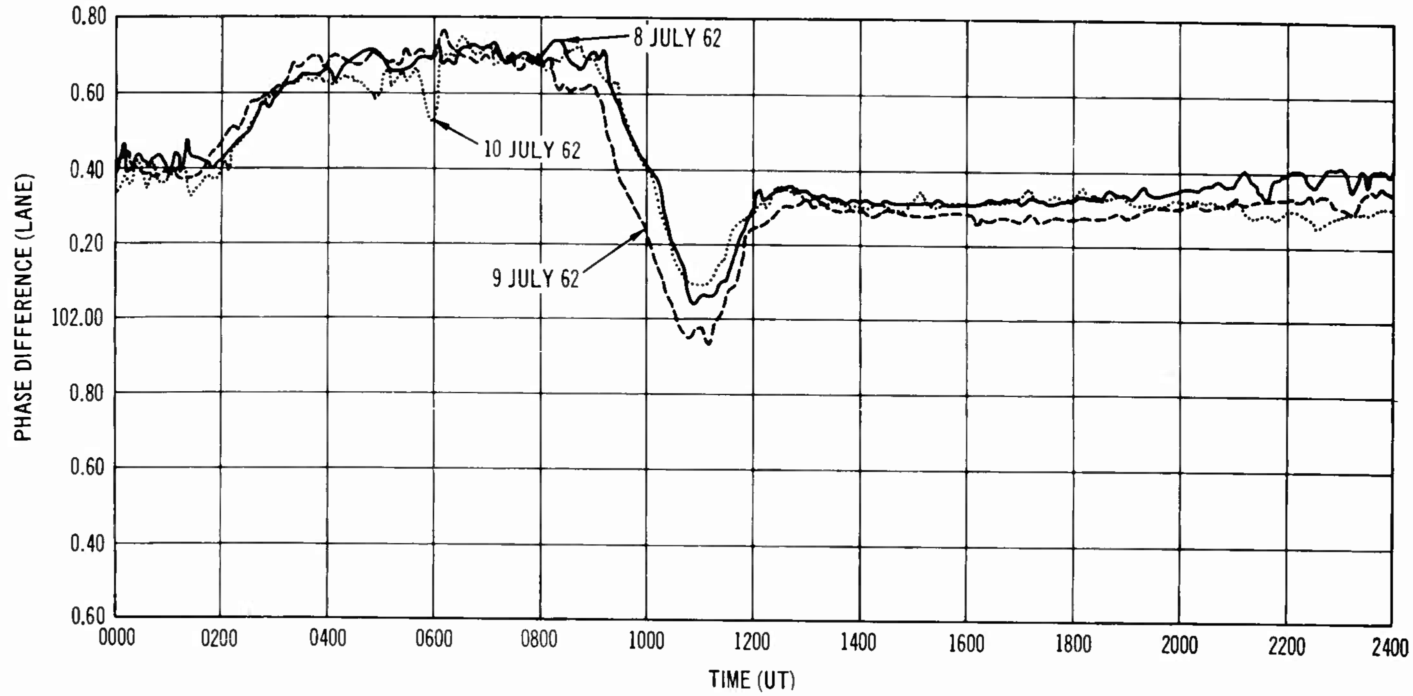

Figure 40. Data from figure 37, plotted for three complete days to illustrate normal day-to-night pattern of phase change.

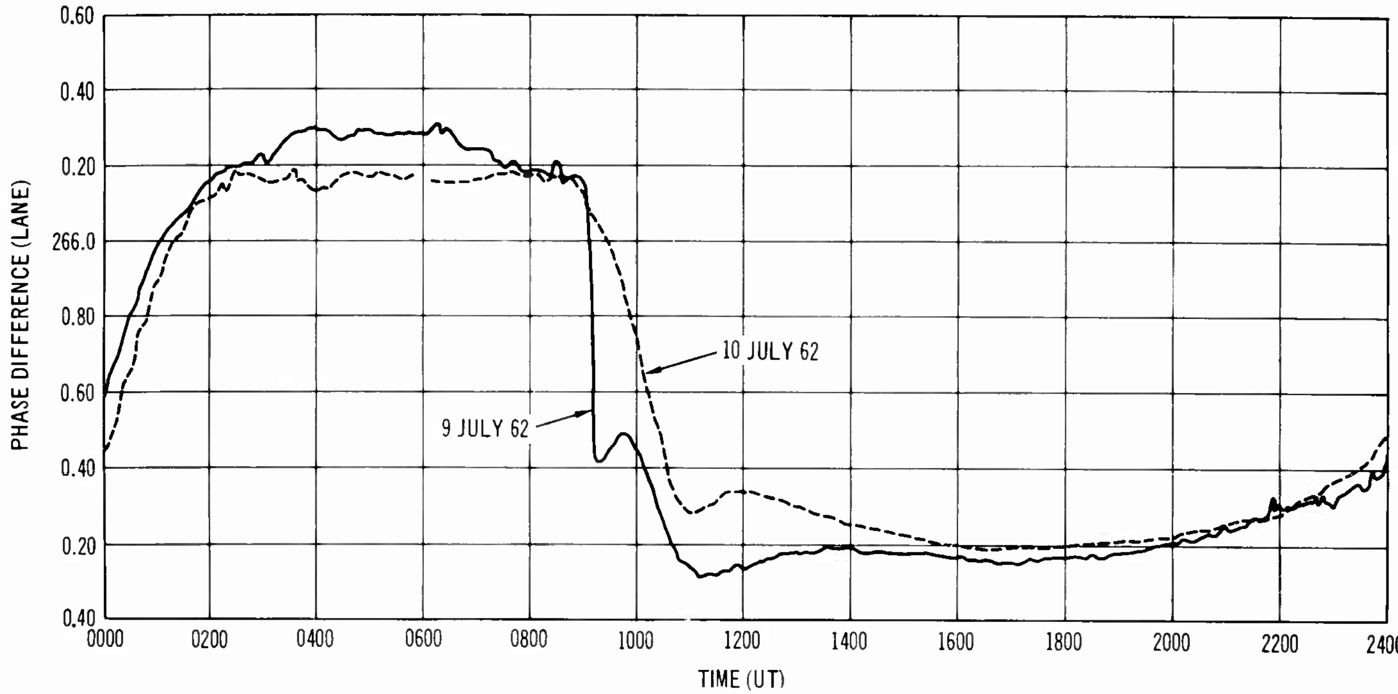

Figure 41. Data from figure 39, plotted for two complete days to illustrate normal day-to-night pattern of phase change.

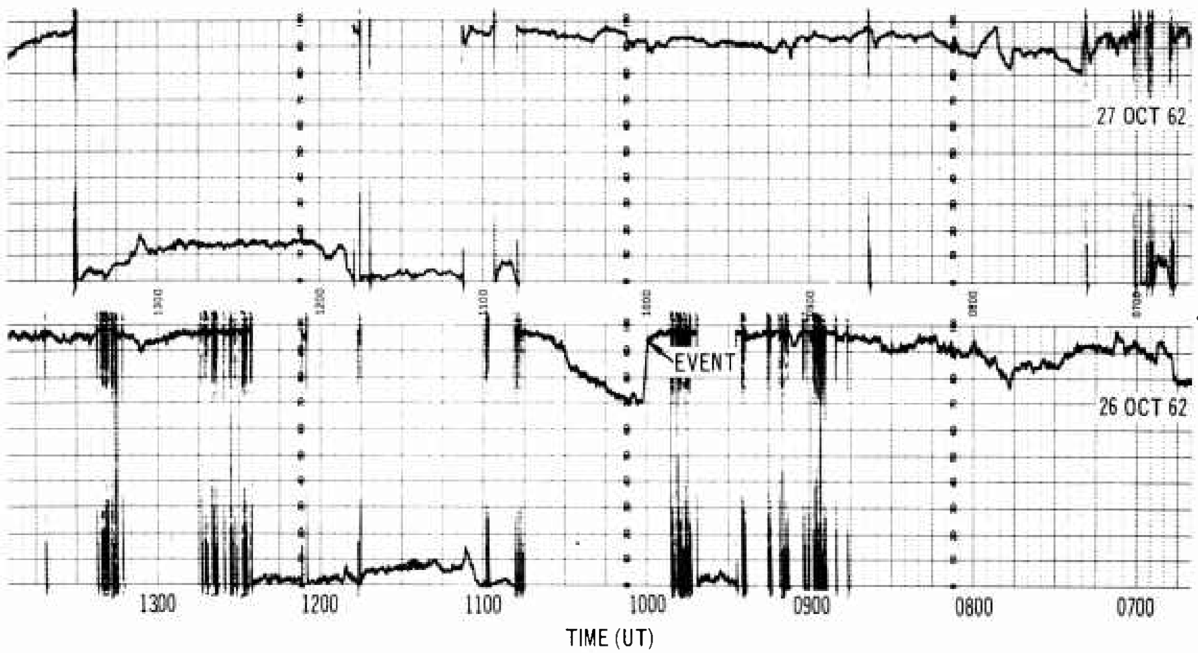

Figure 42. Phase difference between 10.2-kc/s transmissions from Haiku, Hawaii, and Balboa, C.Z. (Haiku minus Balboa), recorded at College, Alaska, 26-27 October 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1). No data available for 24 Oct 62.

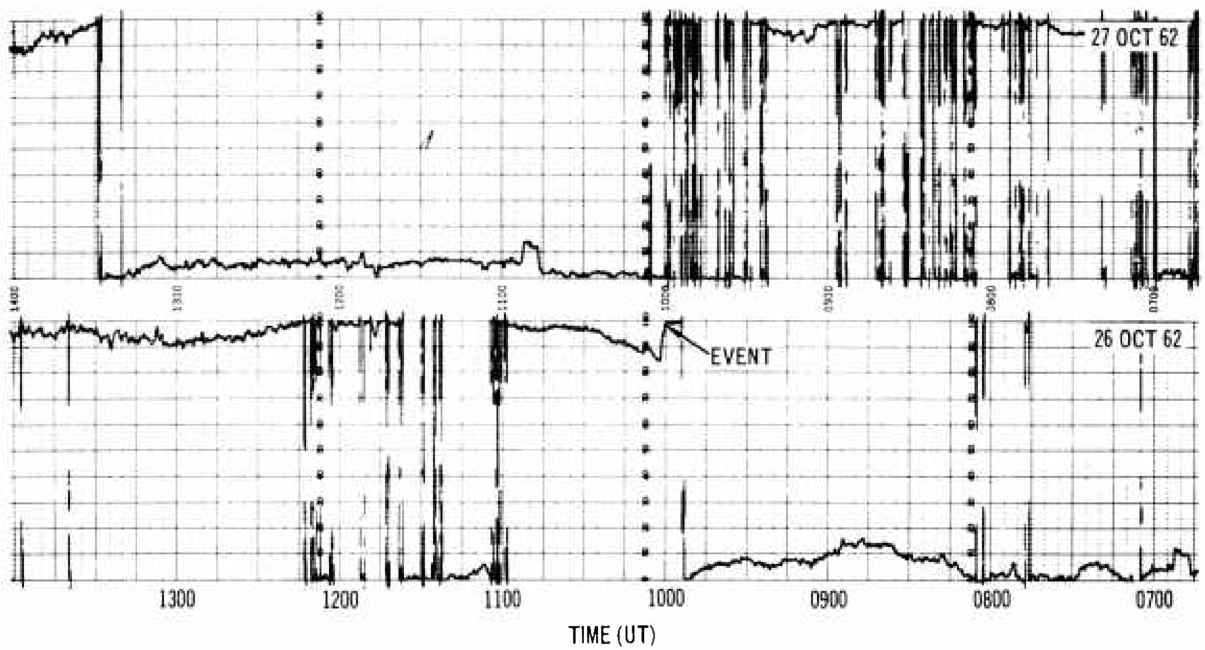

Figure 43. Phase difference between 10.2-kc/s transmissions from Haiku, Hawaii, and Balboa, C.Z. (Haiku minus Balboa), recorded at Whidbey Is., Wash., 26-27 October 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1). No data available for 25 Oct 62.

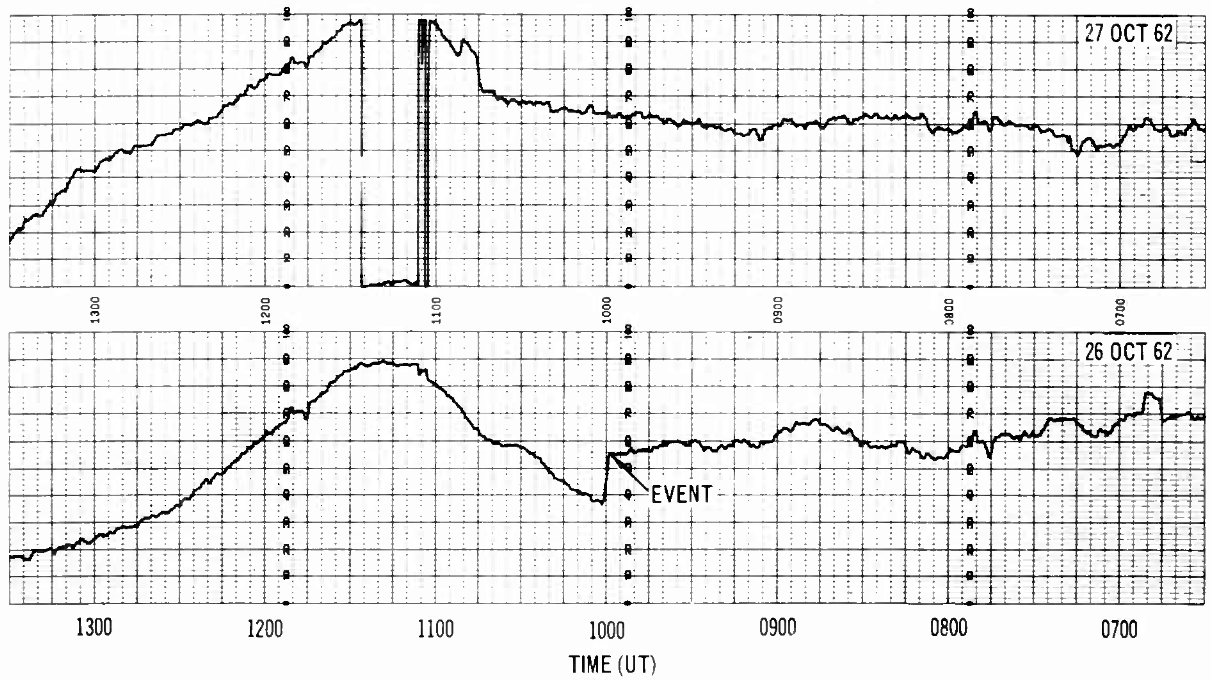

Figure 44. Phase difference between 10.2-kc/s transmissions from Haiku, Hawaii, and Balboa, C.Z. (Haiku minus Balboa), recorded at Rome (Forestport), N.Y., 26-27 October 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1). No data available for 25 Oct 62.

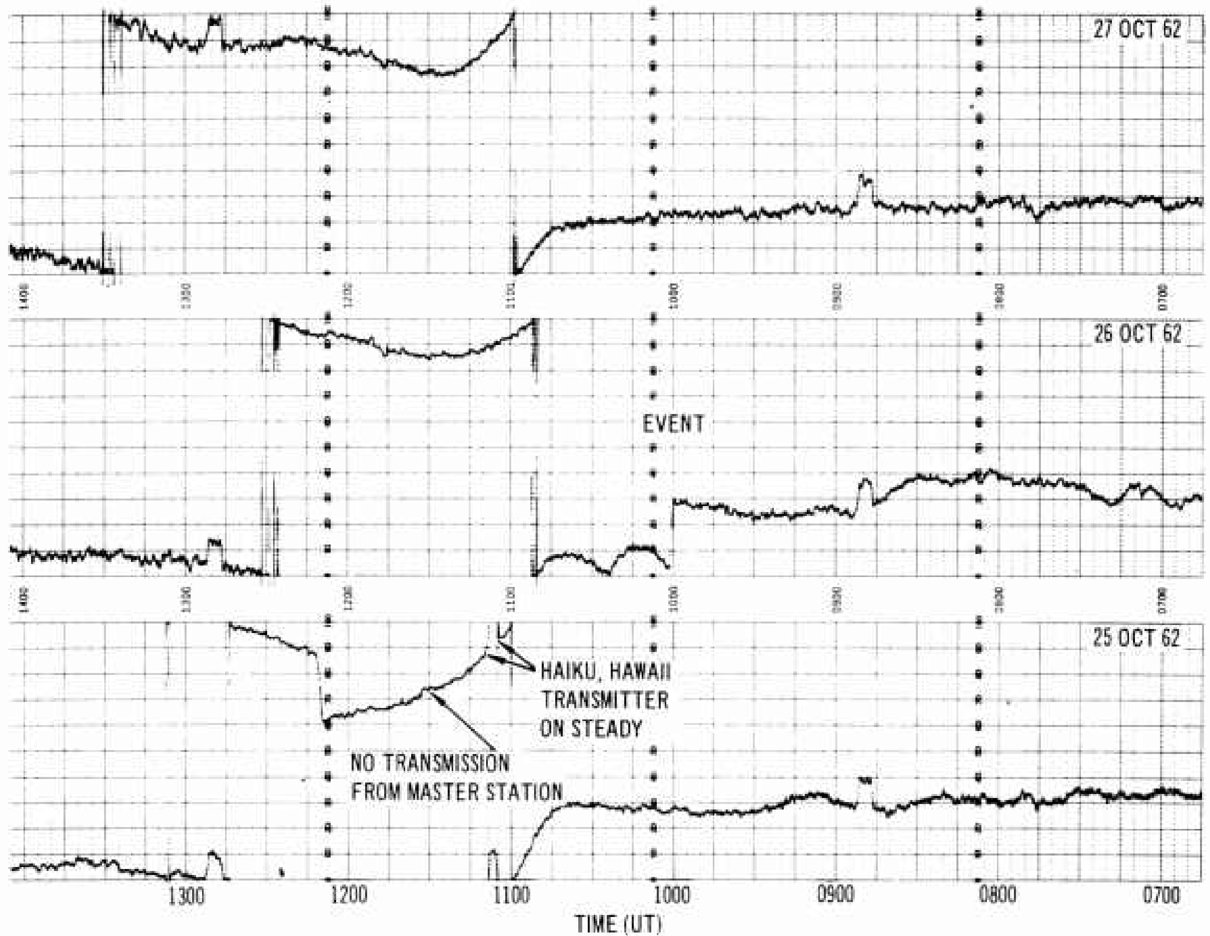

Figure 45. Phase difference between 10.2-kc/s transmissions from Forestport, N.Y., and Balboa, C.Z. (Forestport minus Balboa), recorded at Opana, Hawaii, 25, 26, 27 October 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1).

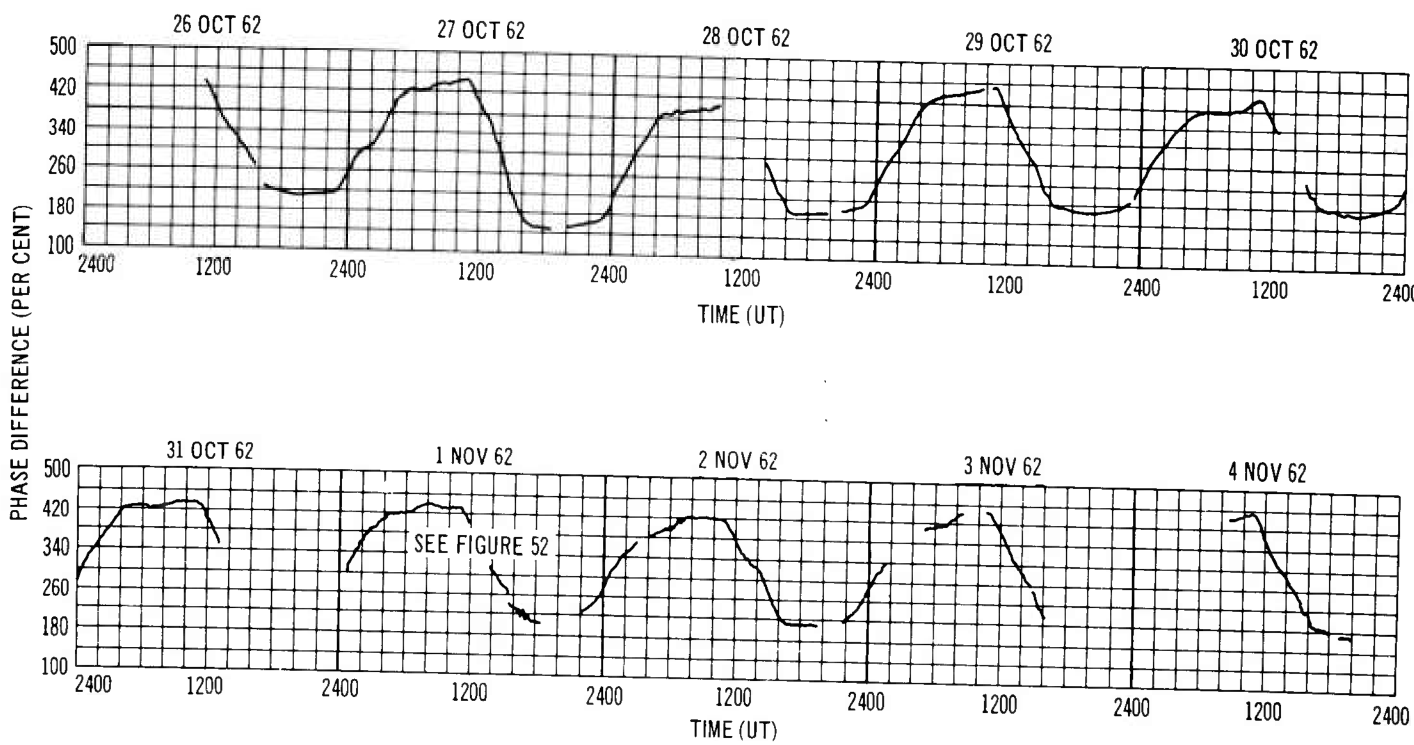

Figure 46. Phase difference data, 10.2-kc/s transmissions from Haiku, Hawaii, and Balboa, C.Z. (Haiku minus Balboa), 26 October through 4 November 1962, recorded at Farfan, C.Z., showing "round-trip" propagation from Balboa to Hawaii and back.

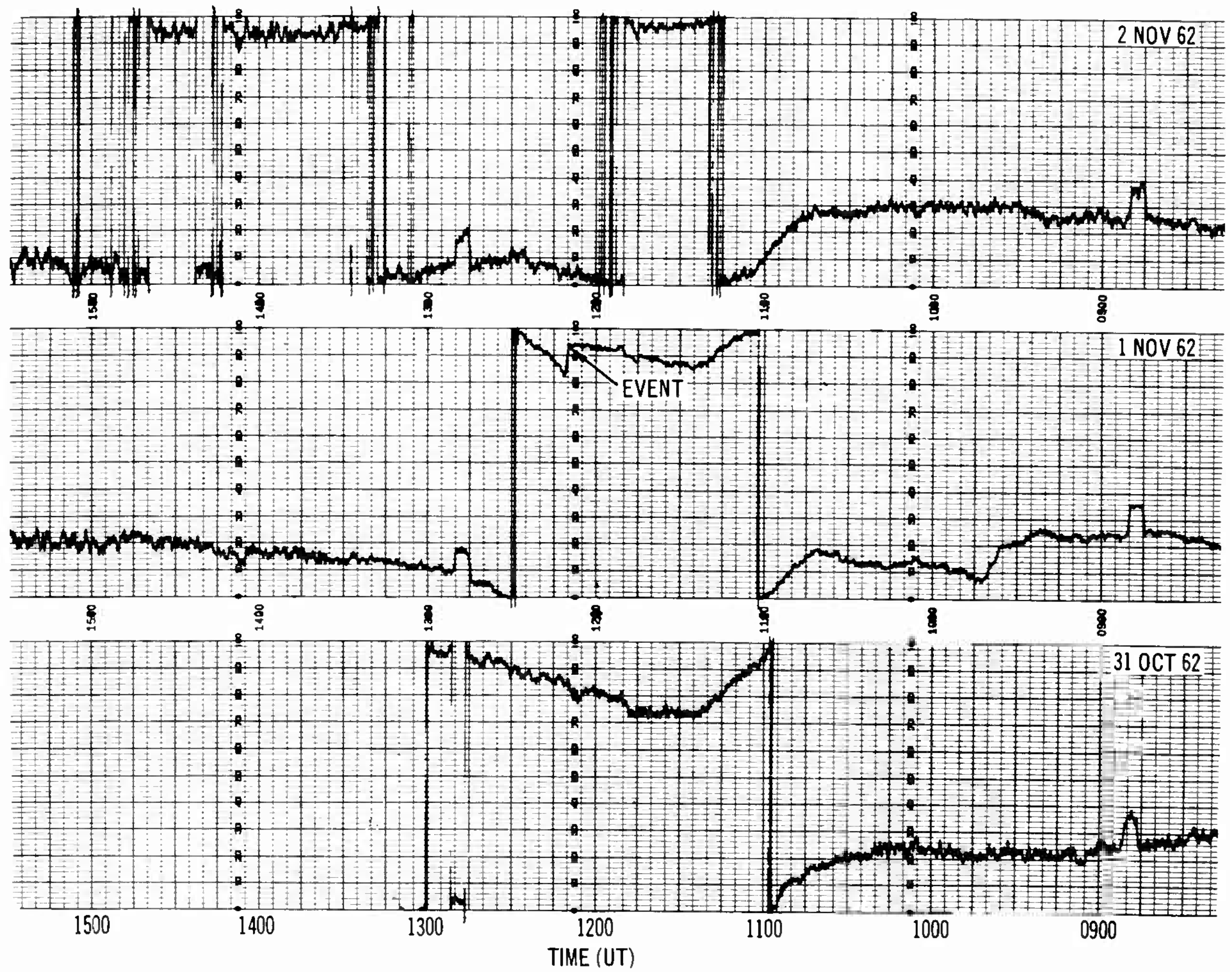

Figure 47. Phase difference between 10.2-kc/s transmissions from Forestport, N.Y., and Balboa, C.Z. (Forestport minus Balboa), recorded at Opana, Hawaii, 31 October and 1-2 November 1962. Scale, 1 cycle full scale; receiver, AN/URN-18 (XN-1).

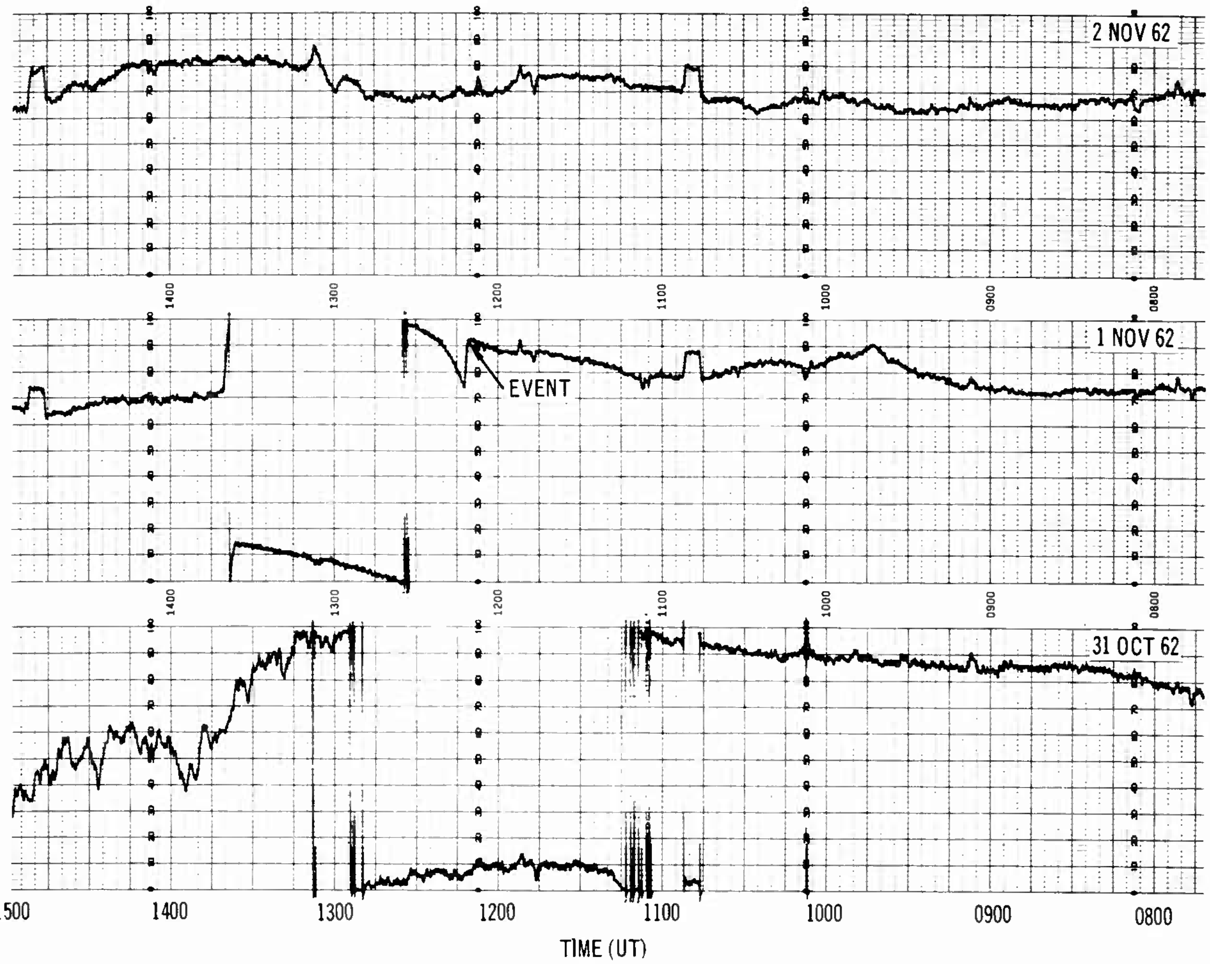

Figure 48. Phase difference between 10.2-kc/s transmissions from Haiku, Hawaii, and Balboa, C.Z. (Haiku minus Balboa), recorded at College, Alaska, 30 October and 1 and 2 November 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1).

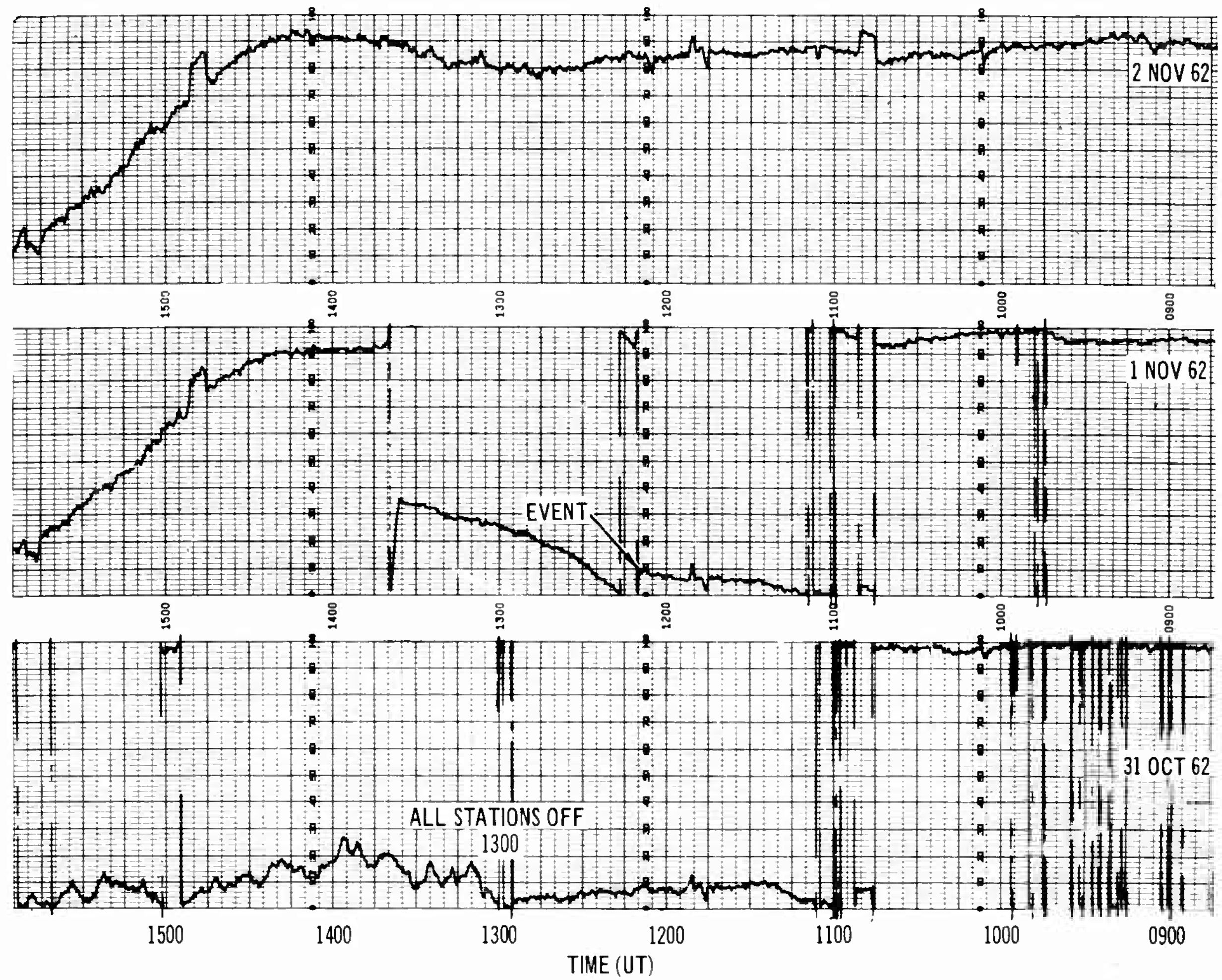

Figure 49. Phase difference between 10.2-kc/s transmissions from Haiku, Hawaii, and Balboa, C.Z. (Haiku minus Balboa), recorded at Whidbey Island, Washington, 31 October and 1-2 November 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1).

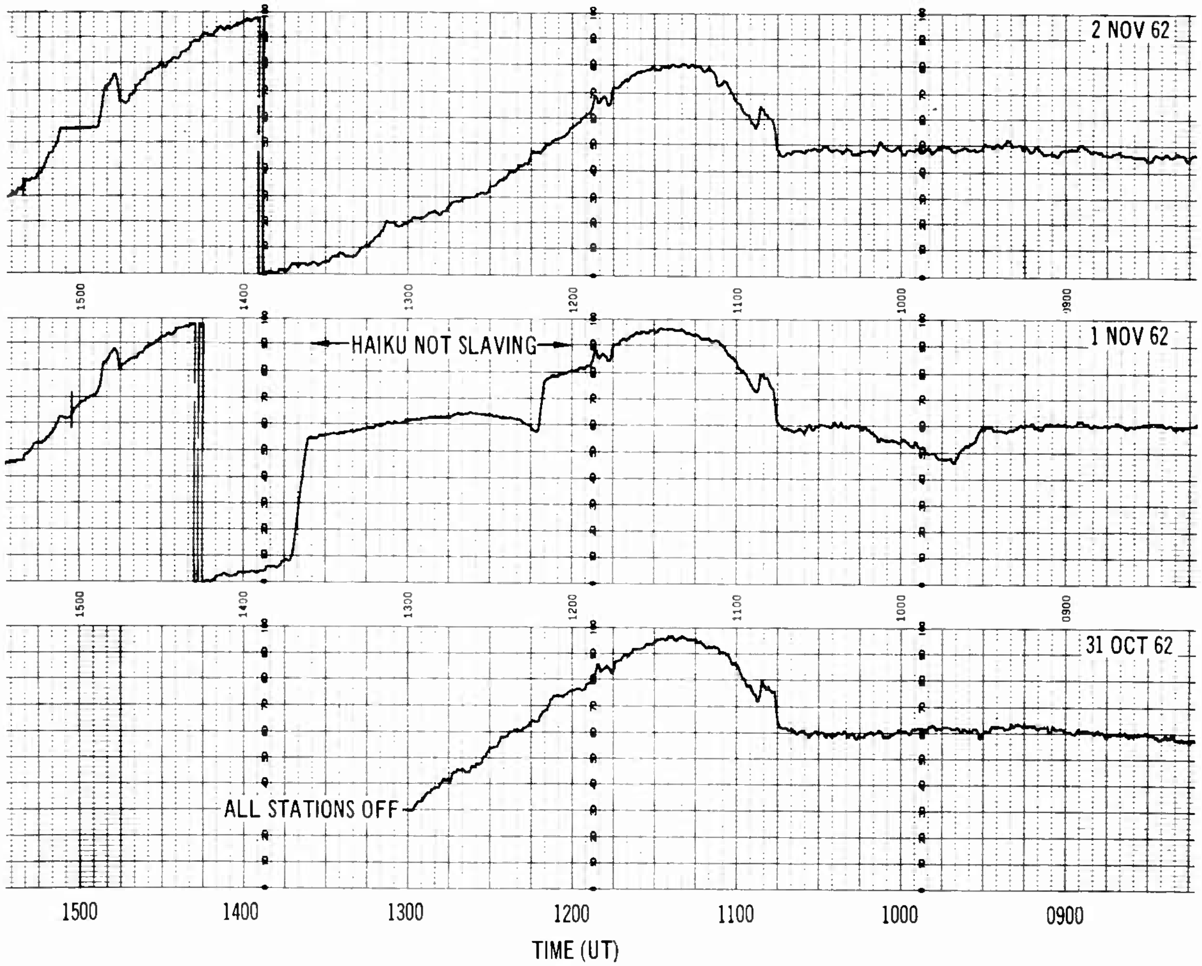

Figure 50. Phase difference between 10.2-kc/s transmissions from Haiku, Hawaii, and Balboa, C.Z. (Haiku minus Balboa), recorded at Rome, N.Y., 31 October and 1-2 November 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1).

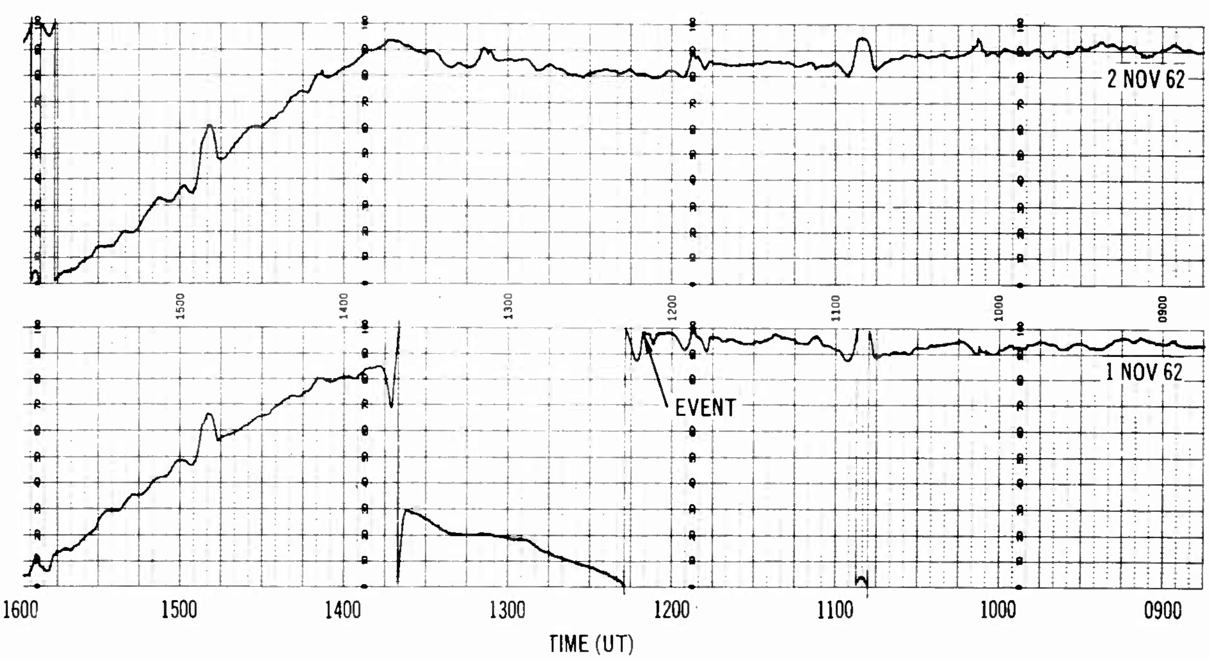

Figure 51. Phase difference between 10.2-kc/s transmissions from Haiku, Hawaii, and Balboa, C.Z. (Haiku minus Balboa), recorded at NEL, San Diego, 1-2 November 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1). No data available for 31 Oct 62.

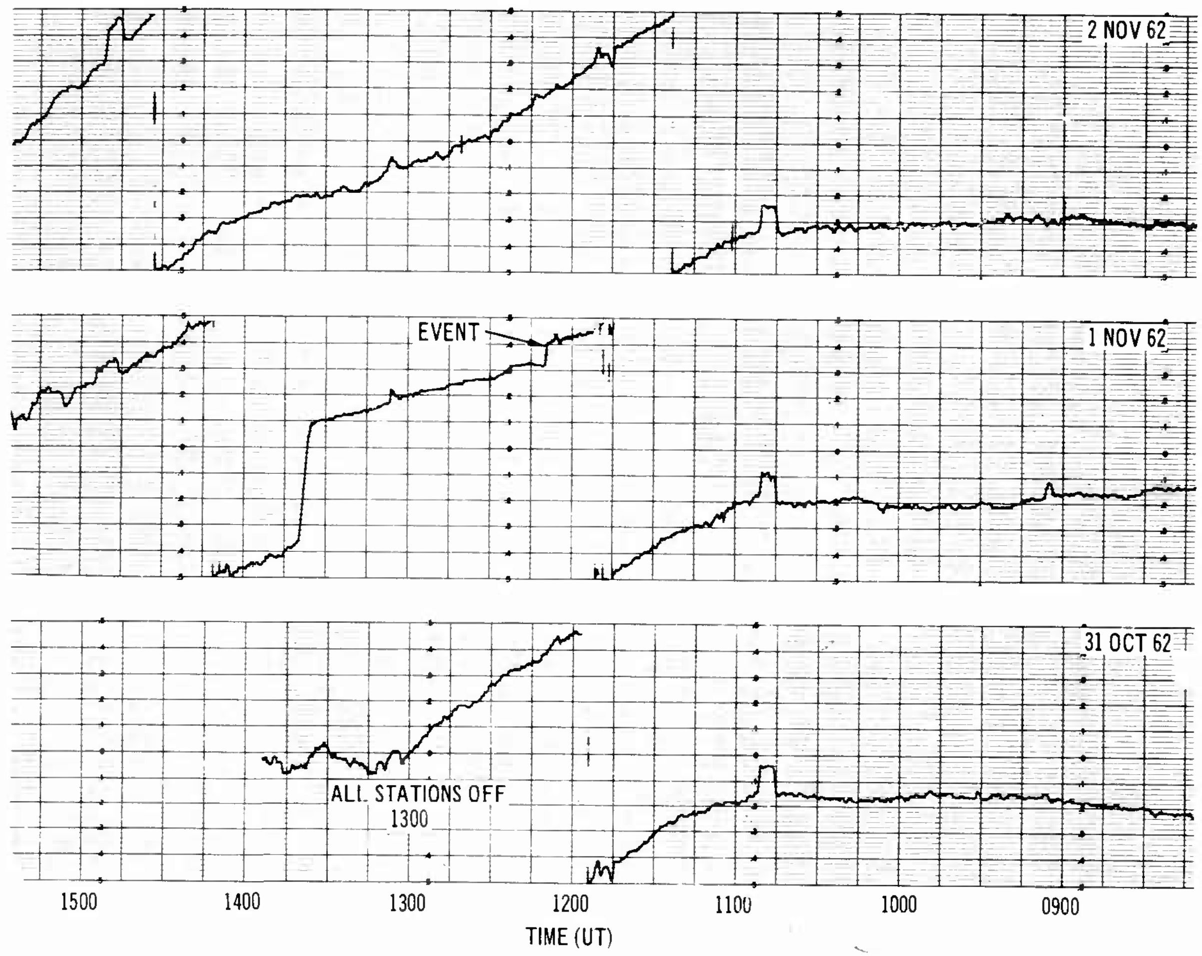

Figure 52. Phase difference between 10.2-kc/s transmissions from Haiku, Hawaii, and Balboa, C.Z. (Haiku minus Balboa), recorded at Farfan, C.Z., 31 October and 1-2 November 1962. Scale, 1 cycle full scale; receiver, AN/URN-18(XN-1).

TABLE 6. SUMMARY OF DATA PRESENTED IN THE PHASE DIFFERENCE RECORDINGS

Fig. No.	Transmission Path	Length of Path (km)	Approximate Distance from Detonation to Nearest Point of Path (km)	Maximum Phase Change Recorded (μsec)	Date and Time of Maximum Phase Change (UT)
37	Forestport minus Balboa at NEL				
	Balboa to Forestport to NEL	7676	5526		
	Balboa to NEL	4666	5526		
38	Forestport minus Balboa at Pt. Barrow				
	Balboa to Forestport to Pt. Barrow	7372	6004		
	Balboa to Pt. Barrow	8595	6004		
39	Forestport minus Balboa at Farfan				
	Balboa to Forestport to Farfan	7685	9118	70	090905 July 62
	Balboa to Farfan	15	9118		
42	Haiku minus Balboa at College, Alaska				
	Balboa to Haiku to College	13306	1357	23	261000 Oct 62
	Balboa to College	8060	5448		
43	Haiku minus Balboa at Whidbey Is.				
	Balboa to Haiku to Whidbey Is.	12756	1357	14	261000 Oct 62
	Balboa to Whidbey Is.	5900	5226		

TABLE 6. (Continued)

Fig. No.	Transmission Path	Length of Path (km)	Approximate Distance from Detonation to Nearest Point of Path (km)	Maximum Phase Change Recorded (μsec)	Date and Time of Maximum Phase Change (UT)
44	Haiku minus Balboa at Rome, New York				
	Balboa to Haiku to Rome	16249	1357	19	261000 Oct 62
	Balboa to Rome	3808	9118		
45	Forestport minus Balboa at Opana				
	Balboa to Forestport to Opana	11665	1357	28	261000 Oct 62
	Balboa to Opana	8452	1357		
47	Forestport minus Balboa at Opana				
	Balboa to Forestport to Opana	11665	1357	12	011210 Nov 62
	Balboa to Opana	8452	1357		
48	Haiku minus Balboa at College, Alaska				
	Balboa to Haiku to College	13306	1357	18	011210 Nov 62
	Balboa to College	8060	5556		
49	Haiku minus Balboa at Whidbey Is.				
	Balboa to Haiku to Whidbey Is.	12756	1357	17	011210 Nov 62
	Balboa to Whidbey Is.	5900	5226		

TABLE 6. (Continued)

Fig. No.	Transmission Path	Length of Path (km)	Approximate Distance from Detonation to Nearest Point of Path (km)	Maximum Phase Change Recorded (μsec)	Date and Time of Maximum Phase Change (UT)
50	Haiku minus Balboa at Rome			18*	011210 Nov 62
	Balboa to Haiku to Rome	16249	1357		
	Balboa to Rome	3808	9229		
51	Haiku minus Balboa at NEL			10	011210 Nov 62
	Balboa to Haiku to NEL	12624	1357		
	Balboa to NEL	4666	5526		
52	Haiku minus Balboa at Farfan			8	011210 Nov 62
	Balboa to Haiku to Farfan	16883	1357		
	Balboa to Farfan	15			

*See figure caption for special conditions.

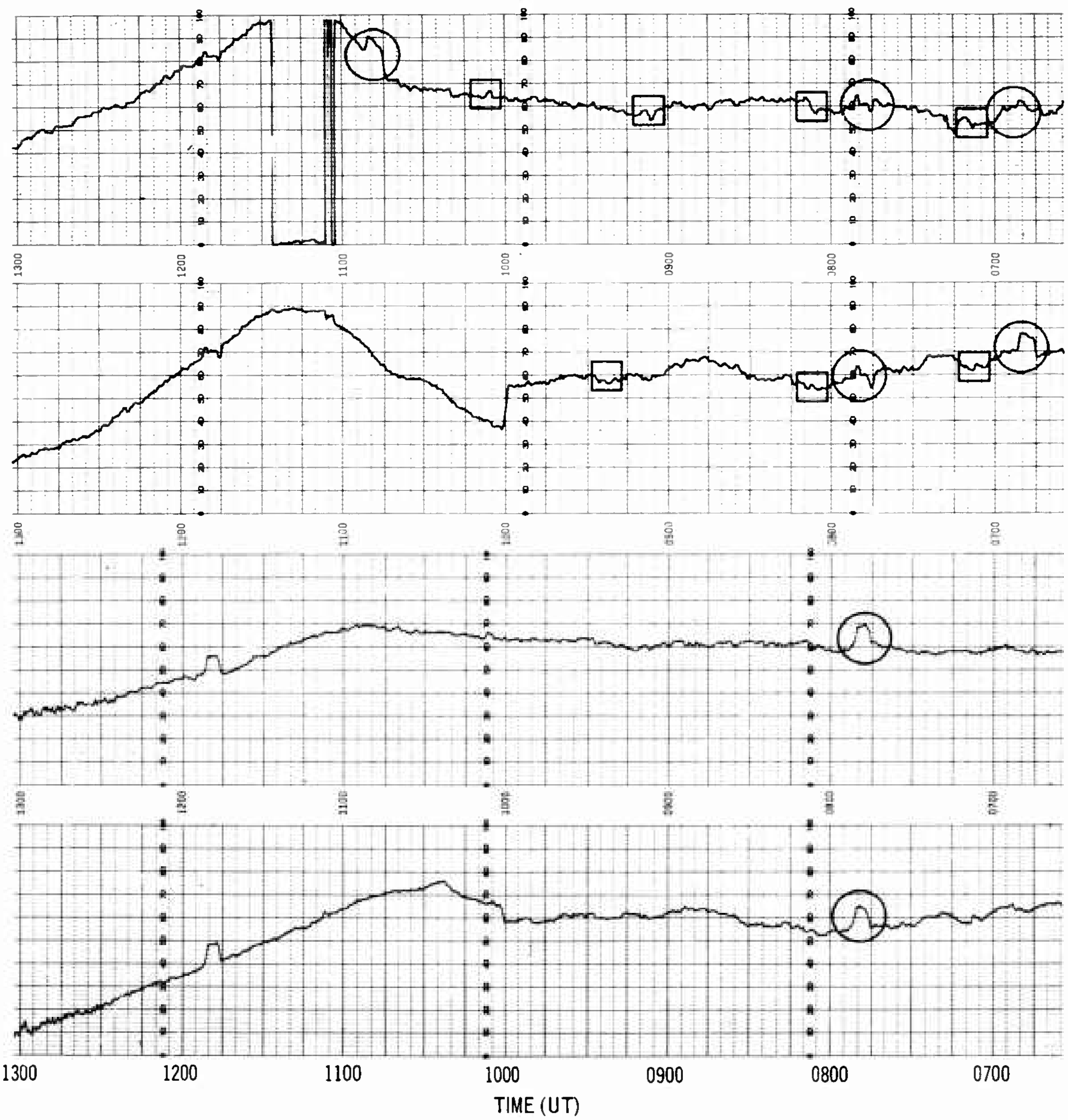

Figure 53. Representative curves illustrating the appearance of signatures and other planned variations. Signatures are marked with circles. Squares indicate times master station was off the air.

CONSTANT-SPEED PHOTOGRAPHS

Figures 54-59 are constant-speed, continuous-motion photographs of the tape recordings of Events BLUEGILL and KINGFISH. A dual-channel recorder was used, with horizontal sync reference signal recorded on one track of the recording tape and the signal on the other.

The signals as recorded on magnetic tape were displayed on an oscilloscope screen using a low-persistency phosphor (P5) tube. The display was photographed using a Fairchild Oscillo-Record camera, which reproduced the traces as lines on 35-mm film. This method has the advantage of eliminating inertial time constants of the system. The film speed for figures 54-59 was 1 inch per second, as compared to 30 inches per second for plotting figure 13.

The phase recordings were photographed by blocking out the face of the oscilloscope, leaving a 3/16-inch viewing slit the width of the screen. The received sine wave display thus appeared as a spot. The slit was aligned with the zero crossing point of the sine wave, with the signal on the vertical plates. Therefore amplitude variations alone did not cause a shift of indicated phase. The film was moved past the camera aperture, no shutter was used, and a line was traced on the film. The position of any point on the line indicates the relative phase of the signal at that time. The wavelength of the sine wave display was approximately 18 cm. The scale indicated on the print makes allowance for print reduction.

Because the signal was received only during Omega time segments, the information is partitioned by bands of noise recordings. Two solid lines were established on the film to provide a reference for comparison.

The intensity recordings were taken by connecting the signal to the horizontal input, so that a horizontal line of varying length was displayed on the oscilloscope screen. The film was then moved by the camera aperture, with shutter open, producing a continuous picture of the r-f envelope. The width of any position indicates the relative intensity of that point. A photographic recording of this same information, with a film speed of 30 in./sec, was used for plotting figure 13. At this speed each individual cycle was identifiable.

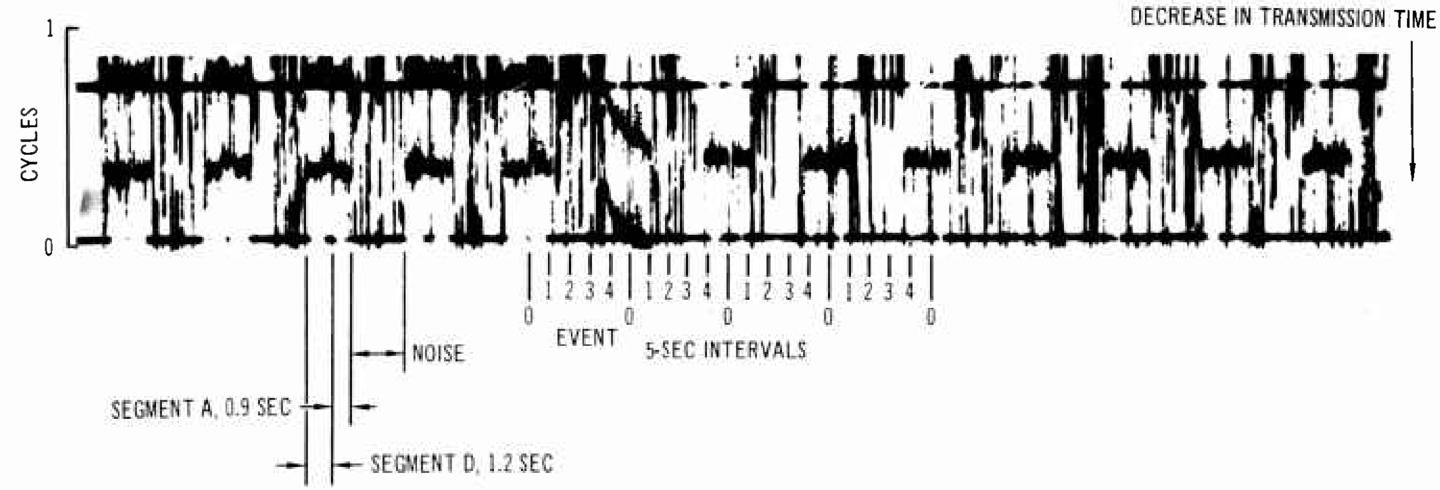

Figure 54. Phase of 14.2-kc/s transmissions from Haiku, Hawaii, 26 October 1962, received at NEL, San Diego, and photographed from tape recordings.

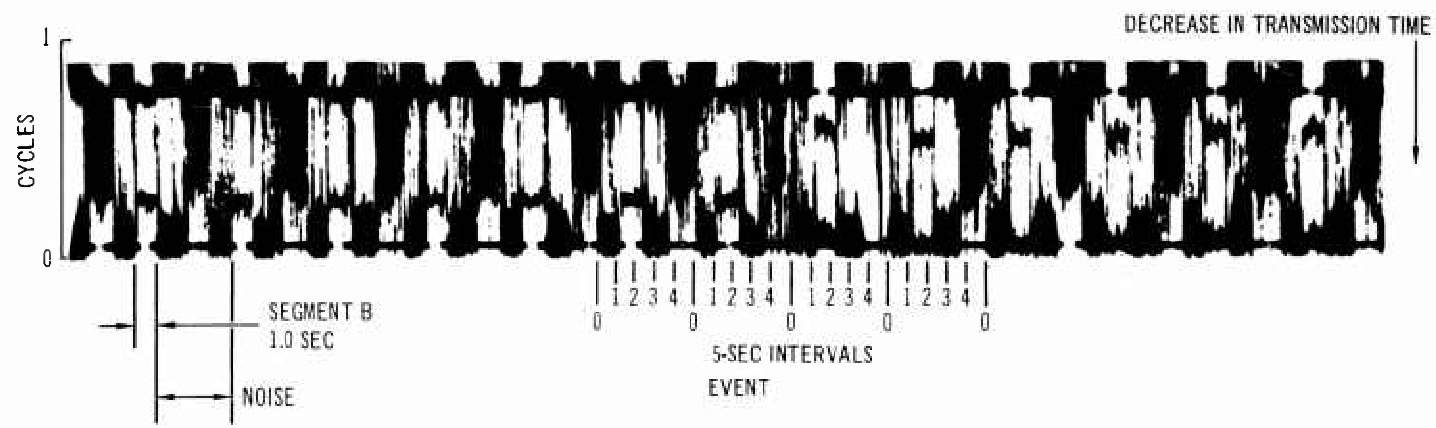

Figure 55. Phase of 10.2-kc/s transmissions from Haiku, Hawaii, 26 October 1962, received at NEL, San Diego, and photographed from tape recordings.

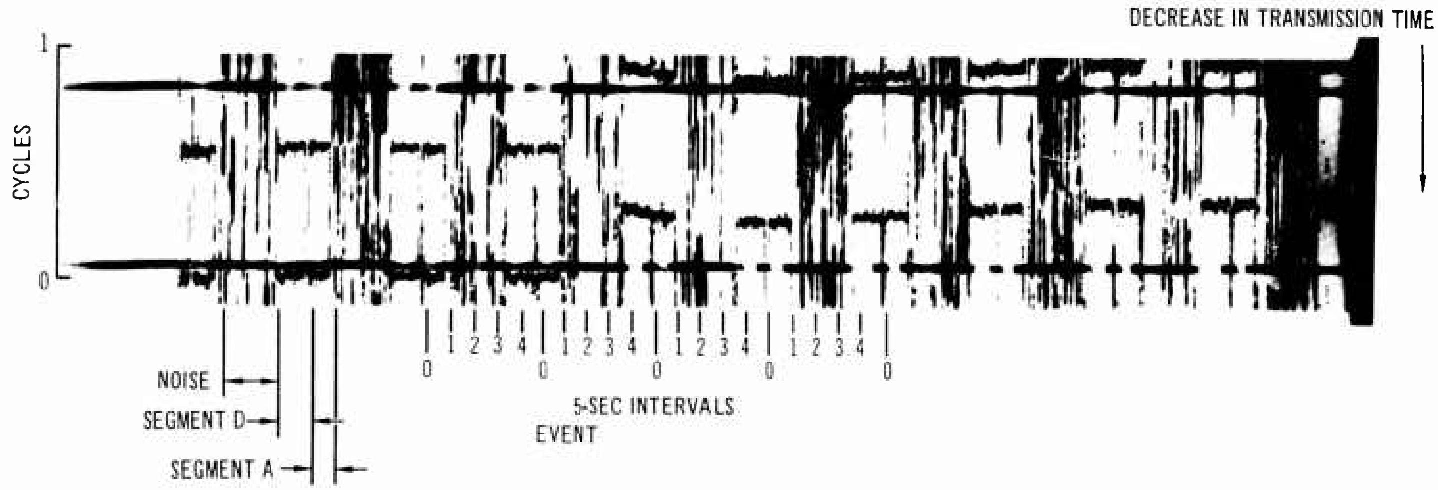

Figure 56. Phase of 14.2-kc/s transmissions from Haiku, Hawaii, 1 November 1962, received at NEL, San Diego, and photographed from tape recordings.

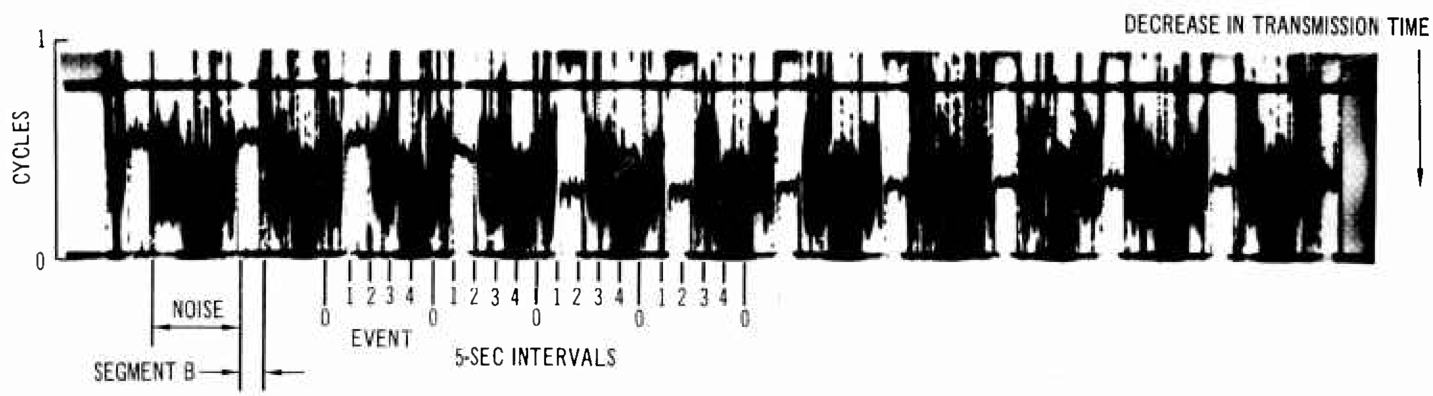

Figure 57. Phase of 10.2-kc/s transmissions from Haiku, Hawaii, 1 November 1962, received at NEL, San Diego, and photographed from tape recordings.

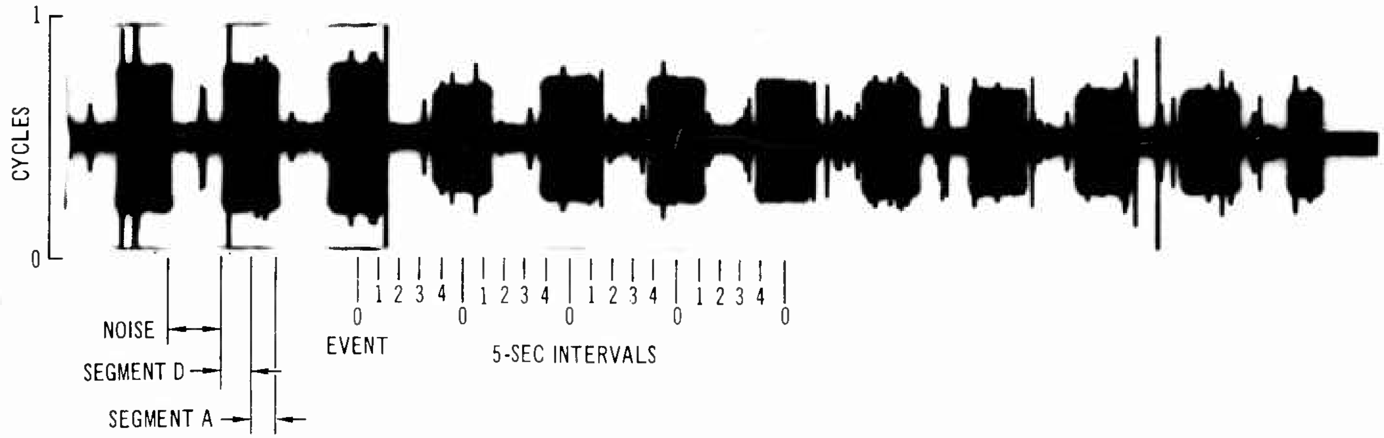

Figure 58. Amplitude of 14.2-kc/s transmissions from Haiku, Hawaii, 1 November 1962, received at NEL, San Diego, and photographed from tape recordings. No calibration; scale is relative only.

Figure 59. Amplitude of 10.2-kc/s transmissions from Haiku, Hawaii, 1 November 1962, received at NEL, San Diego, and photographed from tape recordings. No calibration; scale is relative only.

NOISE RECORDINGS

Figure 60 is a recording of the atmospheric noise taken at NEL during Event STARFISH using an AN/URM-6 field intensity meter at a frequency of 14.2 kc/s, with its loop plane east and west.

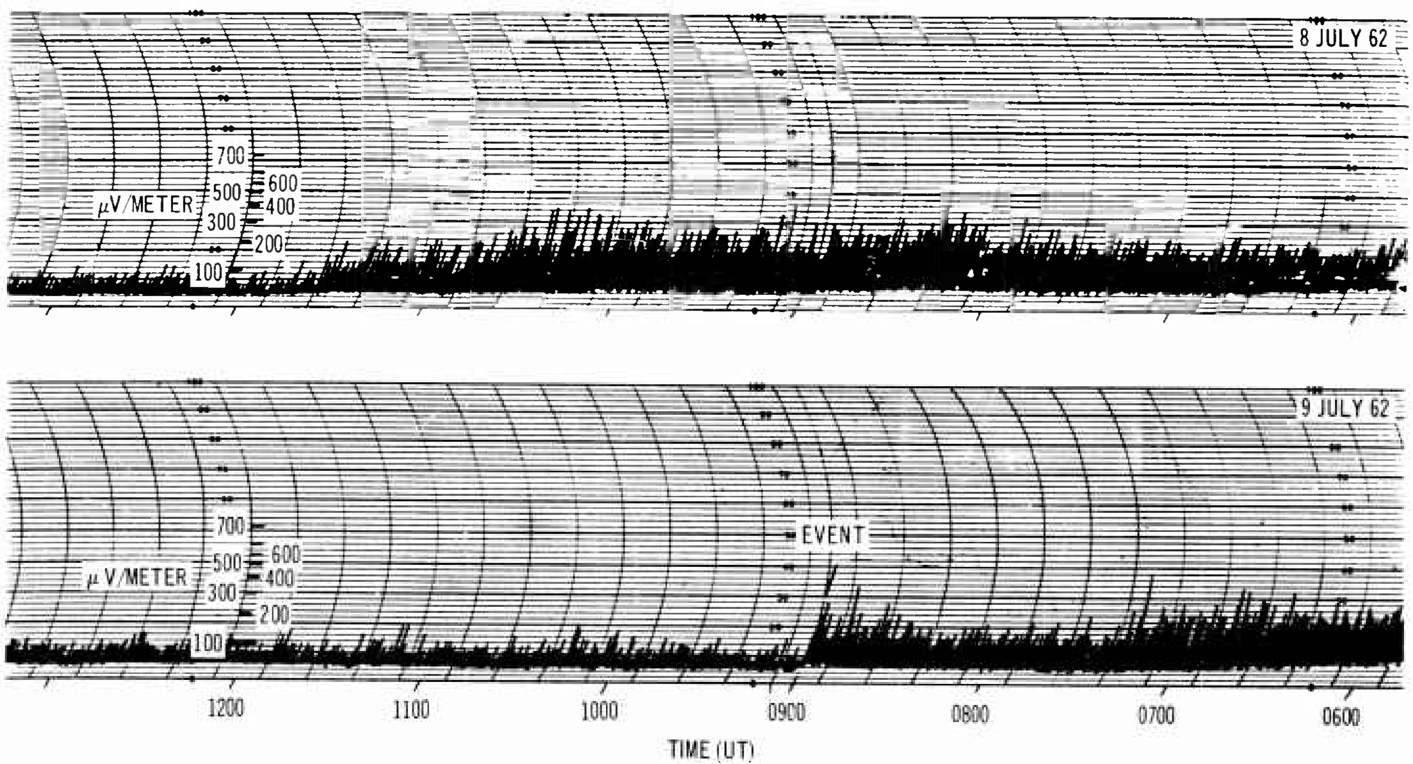

Figure 60. Recording of atmospheric noise taken at NEL, San Diego, 8-9 July 1962, on an AN/URM-6 field intensity meter at 14.2-kc/s frequency with its loop plane east and west. Time, 0600 to 1300 UT; bandwidth, 150 c/s. Scale added to show microvolts/meter.

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Project FISHBOWL Effects on Omega VLF Transmissions, by C. J. Casselman, R. L. Denton, and J. J. Wilson. 72 p., 20 December 1963.

UNCLASSIFIED

Phase and amplitude of Omega signals were studied and recorded during three events of Project FISHBOWL: Event STARFISH (9 July 1962), Event BLUEGILL Triple Prime (26 October 1962), and Event KINGFISH (1 November 1962). Data were not taken during Events CHECKMATE (20 October 1962) or TIGHTROPE (4 November 1962).

The general effect of the events on propagation of Omega signals seems to have been a rapid variation in phase followed by a slow return to normal, sometimes taking more than a week to be completed.

1. Nuclear bomb explosions (High altitude) - Electromagnetic effects
2. OMEGA - Test results
3. Radio navigation systems - Effects of radiation

I. Casselman, C. J.
II. Denton, R. L.
III. Wilson, J. J.

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